Section 22
Massachusetts

# Massachusetts Natural Valley Storage Investigation



August 1993

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# MASSACHUSETTS NATURAL VALLEY STORAGE INVESTIGATION

SECTION 22 STUDY

SPONSORED BY:

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS

AND

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENVIRONMENTAL AFFAIRS

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# EXECUTIVE SUMMARY

The Corps of Engineers was authorized in the Energy and Water Development Appropriations Act of 1991 to conduct a Natural Valley Storage (NVS) investigation for the Commonwealth of Massachusetts under the authority contained in the Section 22, Planning Assistance to States Program. This report is the result of that authorization.

The goal of this study was to research and discuss methodologies to quantify in economic terms the costs and benefits of natural valley storage as a means of reducing future flood damages. Natural valley storage consists of wetlands and floodplains which provide significant flood water retention. The study discusses methodologies to determine benefits including the ecological benefits of natural storage areas and incorporates a case study demonstrating the application of these methodologies. The study, which was conducted using a combination of Federal and state funds, accomplished the following:

- provided a review of Corps flood control projects in New England;
- described the physical characteristics of natural valley storage;
- summarized the Corps' Charles River Natural Valley Storage Project;
- described methodologies to quantify the costs and benefits of natural valley storage;
- and using the Nashua River as an example, conducted a case study which demonstrates the application of some of these methodologies.

The Corps of Engineers has been very active in providing flood control measures in New England. Today there are forty-nine such projects in the State of Massachusetts alone. Eleven of these projects consist of dams and reservoirs, that protect many communities. A hurricane protection barrier is located in New Bedford. The remainder of the flood control projects are categorized as local protection projects, almost all of which are structural in nature. The structural local protection projects include a dam, dikes, floodwalls, channels, and slope stabilization. The one nonstructural local protection project is the Charles River Natural Valley Storage Project. Based on the success of the Charles River Project, the Commonwealth of Massachusetts requested the Corps to conduct this study to look at alternative methodologies which could be used in the evaluation of natural valley storage projects in Massachusetts.

Natural Valley Storage areas are lands that have the ability to temporarily store flood waters. Natural valley storage areas consist of wetlands and floodplains along a lake, stream, or river. As flood waters overtop the banks of the conveying waterbody, they spill over or flood other adjacent areas. If these surrounding areas exhibit natural storage abilities, the flood waters become temporarily entrapped. This temporary storage allows for gradual release of flood water which in turn reduces peak flood stage and discharge downstream. Some areas only store water, while others both store and convey at the same time.

A natural storage area's effectiveness is a function of soil type, topography, and vegetation. Lands consisting of soils that retain water (sands, gravels, and organics) are better suited for natural storage as opposed to land composed of soils that "shed" water (clays). The grade of the land is also a factor. Areas with steep slopes don't make good storage areas. Those with a flatter surface are more apt to retain flood waters. Vegetation directly impacts the roughness of a flow surface also. Areas with much vegetation (wetland, forest) retard water movement; while a paved area offers little resistance and water escapes easily.

A storage area's effectiveness is also dependent on its location in a watershed. Storage areas located in the upper portions (along 1st and 2nd order streams) of a watershed tend to interact with smaller drainage areas and flows. Subsequently, these areas, individually, tend not to have a major impact on flooding downstream. Cumulatively their effect is much greater. A single storage area along a major tributary (3rd or 4th order stream) tends to have a greater individual impact on downstream flooding as these areas usually receive greater drainage areas and flows.

Finally, natural valley storage is more effective in reducing flooding which peaks and recedes quickly. The effect of natural valley storage on long duration flooding is usually less. In a flash flood, natural storage causes a decrease in peak discharge, which can approximate the reduction between inflow and outflow experienced during the rising portion of the event. Its effect on long duration flooding is less effective because during such an event storage capacity is maximized and inflow equals outflow.

Natural valley storage areas not only provide a nonstructural means of flood control, but several other potential values as well. Recreational opportunities often abound in these areas in the form of fishing, hunting, and hiking. This can result in the economic development of the surrounding areas, depending on the nature and scale of recreational usage. One of the major reasons for such recreation use is the natural storage areas' attraction as a habitat for wildlife. Natural storage areas are often used for agricultural purposes or for the harvesting of other commercial products such as timber. Natural storage areas may also provide such things as educational opportunities, erosion control, water quality treatment, groundwater recharge, habitat for rare species of plants and animals, and may enhance surrounding property values.

The Charles River Natural Valley Storage Project is an example of the use of nonstructural means to control flooding. The Corps of Engineers, as the result of a 1972 study recommendation, purchased or established easements on 8,000 acres of land within the Charles River Basin. These lands were determined to be critical for naturally storing flood waters. The primary purpose of the project was the reduction of future flood damages in areas downstream, near Boston. However, the project also has secondary purposes of recreation, and fish and wildlife management. The total annual cost of the project was estimated at $477,000. The annual benefits gained by the project were estimated at $772,000, of which $125,000 was attributed to recreation and the environment. Today the

Charles River NVS Project continues to serve eastern Massachusetts, providing flood protection as well as boating, hiking, and fishing opportunities.

A major part of this study was not only to describe the current methods of determining the costs and benefits of a natural valley storage project, but to go beyond the traditional Corps of Engineers economic analysis and investigate alternative methods. This involved first reviewing Corps of Engineers NVS studies on the Charles, Spicket, and Taunton rivers. The annual costs in all cases involved the purchase of lands and or establishment of restrictions against development. Benefits for the Spicket and Taunton studies were based solely on flood damage reduction, while the Charles River analysis included recreation and environmental benefits as well. The Charles River analysis was also unique in that it projected future increases in flood damages as a result of expected future growth in the flood prone areas along the river. This methodology was able to be used because of the extreme developmental pressures experienced in the early 1970's. Similar assumptions would be difficult to justify today.

A fairly extensive literature search was conducted to investigate other possible methods of quantifying costs and benefits. A complete list of references is contained in the bibliography following the main report. Some other benefit categories that were considered beyond traditional flood damage reduction benefits were the following: recreation, flood insurance savings, recreation induced economic development, enhanced property values, water quality, erosion control, groundwater recharge, commercial products, agriculture, aesthetics, habitat, education, aquatic food chain support, long-term carbon storage, nonuse and total resource values. The damage/cost prevented or unit day value methods were used for calculating traditional benefits. The literature search revealed that there are other methods available such as the travel cost method, contingent value method, replacement cost method, hedonic price technique, market revenues method, and energy analysis technique. The research did not reveal any new methodologies for calculating project costs.

Finally, a case study based on the Nashua River was conducted to demonstrate the cost/benefit analysis using the various methodologies investigated. A hydrologic analysis of the main stem of the River was performed as part of this effort. Over 4,800 acres of natural storage areas were identified. Two damage centers located downstream from the NVS areas were determined. Scenarios of 10 and 30 percent loss of storage were analyzed and found to cause increases in flood stages above existing conditions. For example, the 100-year event flood elevations above Mine Falls Dam increased by 0.6 feet for the 10 percent loss scenario and 1.2 feet for the 30 percent loss scenario. Elevations above Jackson Mills Dam increased by 0.7 feet for the 10 percent loss scenario and 1.7 feet for the 30 percent loss scenario. These increases in stages are a result of increased flood discharge due to the loss of upstream NVS. When analyzing the NVS area for the 30 percent loss scenario some encroachment into the FEMA designated floodway was assumed. This analysis resulted in flood stage increases of over 1 foot throughout much of the NVS area. These increases are due to the effects of reduced flow area and storage volume

along with the resulting increases in flood discharge calculated by the one-dimensional unsteady flow model used in this study.

Examples of calculations to demonstrate development of annual costs and annual benefits were included using gross estimating criteria. Figures developed were intended to illustrate cost and benefit quantification techniques but should not be used as a measure of NVS value within the case study area. That determination would require significant additional investigation. Demonstration level annual costs for land acquisition for the 10 and 30 percent loss scenarios and annual benefits for flood damage reduction, recreation, flood insurance savings, and commercial products are described. Gross values for agriculture, long-term carbon storage, wetland replacement, and energy output were also calculated. These values could not be converted to a comparable annual form or were found to not be true measures of a project benefit. For example, loss of agricultural lands may just cause a change in the goods produced by the land or, as in long-term carbon storage, gross values overstate potential benefits as not all the value is lost with development. Some procedures like the contingent value and replacement cost methods were seen as potentially valuable tools for measuring benefit categories like water quality, groundwater, erosion control, habitat value, and total resource value. However, implementation of these methods was found to be data intensive, and data was not readily available during the case study. Nevertheless, these methods appear to be viable and were described in detail for future use.

As a result of this study several recommendations were made. The Commonwealth of Massachusetts should continue to proceed along a path of providing protection of its natural valley storage lands through regulations such as the Wetlands Protection Act and the National Flood Insurance Program. Although this may not completely address the loss of natural valley storage areas, in many cases the proper enforcement of existing Federal and state regulations can avoid the need for outright acquisition of storage lands.

The research performed as part of this investigation identified several methodologies that can be used to evaluate the economic value of preserving natural valley storage. However, as was demonstrated in the Nashua River Case Study, application of these methods can involve a significant amount of data collection, evaluation, and uncertainty. This report recommends that a preliminary screening effort be conducted to identify significant natural valley storage areas within Massachusetts. This screening effort should include: identification of floodplain areas upstream of large potential damage centers, a determination of each areas' ability to store floodwaters, an evaluation of the areas' potential risk to development, and an inventory of potentially impacted natural resources. Risk to development would include an evaluation of the laws and regulations protecting the areas, the historical amount of these lands being lost to development and an evaluation of current and future development pressures in the region. Any detailed evaluations, similar to those described in this report, should only be conducted for those areas which are shown to be favorable through the screening process.

There appear to be several different methods (travel cost, contingent value, replacement cost, market value) available for quantifying less traditional benefit values in planning studies. These methodologies should be utilized wherever possible. Corps of Engineers' studies, given the necessary information, could also use these methods to calculate benefits, within the guidelines set forth by regulations.

The results of the case study identified a lack of transferable information regarding the relationship between water quality and groundwater recharge and the preservation of natural valley storage. Information on this relationship exists in other parts of the country, but that literature and its conclusions are not readily transferrable to this region. Without an understanding of this relationship in the Northeast, a benefit calculation is impossible. Coordination with the United States Geological Survey confirmed this lack of data. Further studies of the relationships of groundwater and water quality to natural storage could be useful to future NVS studies. Based on what is known now it is apparent that each site is unique and needs to be studied on an individual basis.

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# 1. INTRODUCTION

## STUDY AUTHORITY

This study was conducted by the New England Division of the U.S. Army Corps of Engineers at the request of the Commonwealth of Massachusetts, Executive Office of Environmental Affairs. The Corps of Engineers was authorized in the Energy and Water Development Appropriations Act of 1991 to conduct a Natural Valley Storage investigation for the Commonwealth of Massachusetts under the authority contained in the Section 22, Planning Assistance to States Program. The Section 22 program authorizes the Corps to assist the states in preparation of plans for the development, utilization, and conservation of water resources.

## STUDY PURPOSE AND SCOPE

The purpose of this study is to research and discuss methodologies to quantify the costs and benefits of natural valley storage as a flood control alternative to structural solutions. Natural valley storage areas are wetlands or floodplains which provide significant flood water retention. The study outlines the Corps of Engineers' role in flood control, describes the physical aspects of natural valley storage, and discusses its application in a detailed description of the Corps of Engineers' Charles River Natural Valley Storage Project. The study focuses on a discussion of the methodologies for determining the costs and benefits of preserving natural storage areas. A technical literature search was conducted as part of this effort. A case study, using the Nashua River, is presented, which demonstrates the application of some of these methodologies.

## CORPS OF ENGINEERS FLOOD CONTROL MISSION

As a result of major flooding during the 1920's and 1930's, Congress directed the U.S. Army Corps of Engineers to conduct extensive flood damage reduction plans for the nation. The Flood Control Act (FCA) of 1936 specifically states that the Corps participate in water resource improvements "for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected". Since then, various legislation has been passed in order to expand on the Corps' continuing mission of flood control.

The Flood Control Act of 1944, the Federal Water Project Recreation Act of 1965, and the Water Resources Development Act (WRDA) of 1986 all state that recreation as a project purpose will be included as part of the planning and development of water resource projects. The FCA of 1944 specifically authorized the Corps of Engineers to construct, maintain, and operate public park and recreational facilities within reservoir areas. Recreation features (i.e., campgrounds, access roads, beaches, swimming and boating facilities, hiking paths, etc.) are to be included as part of the projects to the extent they do not interfere with the project's primary goal of flood control. Current Army policy also states

that high priority be accorded to those projects that involve flood control, commercial navigation, and the restoration and protection of environmental resources. Recreation is considered a low priority output and, to the extent that it is used, effects the priority ranking of new construction start candidates.

Water supply augmentation, as it applies to the Corps' flood control mission, is not as liberal. The Water Supply Act of 1958 and WRDA of 1986 state that the Federal government may develop water supplies in connection with water resource improvements associated with flood control purposes. Specifically, the Corps of Engineers was directed to provide additional storage for municipal water supply in reservoirs, provided the non-Federal sponsor pays 100% of the additional cost. The Water Pollution Control Act of 1961 also directs the Corps to improve water quality and streamflow regulation as part of its flood control mission. Regulations require that the non-Federal sponsor contribute 25% of the costs associated with water quality improvements. Again, these directives can be accomplished as part of a flood control project, but are never the sole basis for a project's construction.

Another feature included in the Corps' flood control mission is the conservation and improvement of fish and wildlife. The Fish and Wildlife Coordination Act of 1958, as amended, and the Federal Water Project Recreation Act of 1965, as amended, state that fish and wildlife conservation and improvement opportunities be fully considered as part of <u>Federal flood control</u> or multipurpose water resource projects. Again, regulations require that the non-Federal sponsor contribute 25% of the costs associated with fish and wildlife improvements. Types of improvements can include, but are not limited to, the following: fencing, selective cutting, planting of food cover, species relocation, wetland restoration and creation, land acquisition, and enforcement of protective regulations. Regulations promulgated under the Clean Water Act (Section 404) also insure that Corps projects minimize wetland impacts. These and the National Environmental Policy Act of 1969 ensure that wetland protection and enhancement are fundamental in the planning, design, and construction of flood control projects.

## TYPES OF FLOOD CONTROL SOLUTIONS

Within a flood control project there can be one or more project purposes. Project purpose refers to the reason or reasons for which a project was authorized or constructed. A single purpose project would be one which provided only flood damage reduction, navigation, or shore protection. An example of a multi-purpose project would be one which reduced flood damages as well as provide additional purposes of recreation, water supply, fish and wildlife conservation, and/or hydroelectric power.

Within the Corps' mission of flood control there are two types of solutions that can be formulated, structural and nonstructural. Structural solutions are those measures that include dams with reservoirs, dry dams, channels, dikes, walls, diversion channels, ice-control structures, and bridge modifications. The intent of these solutions is to reduce the frequency and/or the amount of damaging flows. Nonstructural solutions must be equally included as part of the formulation process. The intent of nonstructural solutions is to reduce flood damages without changing the nature or extent of the flooding. Nonstructural solutions can include floodproofing, permanent relocation of structures, flood warning and preparedness systems, and purchase or regulation of floodplain lands. Floodproofing includes measures such as elevating buildings, relocating or protecting damageable property within the building, sealing walls, protecting utilities, temporary or permanent closures, and installing pumps and valves. Flood warning systems usually consist of gages that determine the extent of the threat, evacuation routes and centers, and detailed mapping. Though the regulation of floodplain lands is a local responsibility, the Corps can provide technical assistance and guidance to local governments in developing floodplain regulations in conjunction with a flood control project.

**FLOOD CONTROL PROJECTS IN MASSACHUSETTS**

The Corps of Engineers has forty-nine flood control projects in the State of Massachusetts. They are classified into three groups: dams and reservoirs, the hurricane protection barrier at New Bedford, and local protection projects. A list of the projects is shown in Table 1.

Almost all the Corps' flood control projects in Massachusetts are structural solutions. The local protection projects, which provide protection to specific communities, consist almost solely of a combination of dikes, floodwalls, slope protection, debris removal, and channelization. The one nonstructural local protection project in Massachusetts is the Charles River Natural Valley Storage Project which consists of land acquisitions to preserve flood storage along the Charles River. There is also a local protection project on the Charles River that includes a dam, pumping station, and navigation locks.

All the projects have an authorized project purpose of flood damage reduction. The Littleville Lake project also has an authorized water supply purpose. The Buffumville Lake, East Brimfield Lake, Tully Lake, and Westville Lake projects have recreation features which were developed by the Corps under the authority contained in the 1944 Flood Control Act.

**PERTINENT FEDERAL AND STATE REGULATIONS**

There are many regulations and guidelines that exist at both the Federal and state levels which pertain to the preservation of natural valley storage areas (floodplains and wetlands).

Federal regulations govern actions such as the discharge of dredge and fill material in wetlands, the beneficial use of and protection of floodplains and wetlands, and the provision of criteria for the placement of solid and hazardous waste in floodplains.

The Federal Emergency Management Agency (FEMA) is a major participant in the preservation of natural valley storage areas. FEMA administers the National Flood Insurance Program (NFIP), which was established in 1968. Under the NFIP, regulations were established to protect floodplains, of which natural valley storage areas are a part. Flood insurance studies were conducted in communities to determine the location of these floodplains, or areas of special flood hazard. FEMA has placed the enforcement of NFIP regulations upon the individual states and communities.

State regulations include such things as design requirements for structures built within the floodplain, criteria for the placement of landfills and treatment plants within the floodplain, designation of encroachment lines along waterways and the management of activities within those areas, protection of scenic and recreational waterways, and the regulation of dredging and disposal activities in wetlands.

A detailed listing of Federal and state regulations and guidelines that pertain to this study is shown in Appendix A.

TABLE 1
FLOOD CONTROL PROJECTS IN MASSACHUSETTS

| PROJECT NAME | RIVER/BROOK | RIVER BASIN | COMMUNITY |
|---|---|---|---|
| DAMS AND RESERVOIRS: | | | |
| Barre Falls Dam | Ware | Connecticut | Barre, Hubbardston, and Rutland |
| Birch Hill Dam | Millers | Connecticut | Royalston, Winchendon, Templeton |
| Buffumville Lake | Little | Thames | Oxford and Charlton |
| Conant Brook Dam | Conant | Connecticut | Monson |
| East Brimfield Lake | Quinebaug | Thames | Holland,Sturbridge, Brimfield |
| Hodges Village Dam | French | Thames | Oxford |
| Knightville Dam | Westfield | Connecticut | Huntington and Chesterfield |
| Littleville Lake | Westfield | Connecticut | Chester and Huntington |
| Tully Lake | Westfield | Connecticut | Royalston and Athol |
| West Hill Dam | West | Blackstone | Uxbridge, Northbridge, and Upton |
| Westville Lake | Quinebaug | Thames | Southbridge and Sturbridge |
| HURRICANE PROTECTION BARRIER: | | | |
| New Bedford | -- | (coastal) | New Bedford and Fairhaven |
| LOCAL PROTECTION PROJECTS: | | | |
| Adams | Hoosic | Hudson | Adams |
| Alford | Green | Housatonic | Alford |
| Amesbury | Powwow | Merrimack | Amesbury |
| Blackstone River | Blackstone | Blackstone | Blackstone |
| Bound Brook | Bound | (coastal) | Scituate |
| Canton | Neponset | Neponset | Canton |
| Charles River Dam | Charles | Charles | Boston |
| Charles River Natural Valley Storage | Charles | Charles | (see Table 2) |
| Chicopee | Connecticut | Connecticut | Chicopee |
| Chicopee Falls | Chicopee | Connecticut | Chicopee |
| Gardner | Mahoney and Greenwood | Connecticut | Gardner |
| Haverhill | Merrimack and Little | Merrimack | Haverhill |
| Hayward Creek | Hayward | (coastal) | Quincy and Braintree |
| Holyoke | Connecticut | Connecticut | Holyoke |
| Housatonic River | Housatonic | Housatonic | Pittsfield |
| Housatonic River | Housatonic | Housatonic | Sheffield |
| Huntington | Westfield | Connecticut | Huntington |
| Island Avenue | -- | (coastal) | Quincy |
| Lee | Housatonic | Housatonic | Lee |
| Little River Dike | Little | Connecticut | Westfield |
| Lowell | Merrimack | Merrimack | Lowell |
| North Adams | Hoosic | Hudson | North Adams |
| North Nashua River | North Nashua | Merrimack | Fitchburg |
| North Nashua River | North Nashua | Merrimack | Lancaster |
| Northampton | Connecticut | Connecticut | Northampton |

TABLE 1 (Continued)
FLOOD CONTROL PROJECTS IN MASSACHUSETTS

| PROJECT NAME | RIVER/BROOK | RIVER BASIN | COMMUNITY |
|---|---|---|---|
| LOCAL PROTECTION PROJECTS: (Continued | | | |
| Riverdale | Connecticut | Connecticut | West Springfield |
| Saxonville | Sudbury | Merrimack | Framingham |
| Sheffield | Housatonic | Housatonic | Sheffield |
| Smelt Brook | Smelt | (coastal) | Weymouth and Braintree |
| South River | South | Connecticut | Conway |
| Springdale | Connecticut | Connecticut | Holyoke |
| Springfield | Connecticut | Connecticut | Springfield |
| Three Rivers | Quaboag, Ware and Chicopee | Connecticut | Palmer |
| Ware | Ware and Muddy | Connecticut | Ware |
| West Springfield | Connecticut | Connecticut | West Springfield |
| West Warren | Quaboag | Connecticut | West Warren |
| Worcester Diversion | Hull and Blackstone Leesville Pond | Blackstone | Auburn and Millbury |

## 2. PHYSICAL DESCRIPTION OF NATURAL VALLEY STORAGE

### HYDROLOGY OF NATURAL STORAGE AREAS

Natural valley storage (NVS) are areas within a watershed that have the capacity to temporarily store water during a time of flooding. NVS areas usually consist of wetlands or floodplain along some water body such as a pond, lake, stream, or river. As waters rise during a flooding event, the water overtops the banks of the conveying waterbody, spilling over into surrounding lands. If the surrounding topography as well as river slope and hydraulic conditions permit, floodwaters can become temporarily entrapped. This detention of water allows floodwaters to recede gradually, creating a lag and reduction in peak flood discharge at the outlet or downstream of the storage areas.

A graphical representation of the hydrologic effect of NVS reducing peak flood discharges can be seen in Figure 1. The typical flood hydrograph shows the relationship between discharge and time. The hatched area "A" represents the amount of water stored in a particular reach. It is equal to the hatched area "B" which represents the amount of water released from the reach. As shown, the effect of NVS is to cause a lag and reduction in the peak discharge.

The greater the amount of storage in a watershed the better its capacity to hold back floodwater, release it slowly, and reduce floodflows. An example of this can be seen when the discharges of the Charles River and Blackstone River, during the 1955 flood, are compared. The Charles River, which contains substantial amounts of storage area, had a peak discharge of 17.5 cubic feet per second per square mile (csm). The Blackstone River, which does not have a significant amount of storage, had a peak discharge of 121 csm.

Individual storage areas within a watershed usually exhibit differing storage capacities. The use of flood hydrographs enables the hydrologist to evaluate a storage area's capacity for handling floodwaters. Figure 2 shows two inflow and outflow hydrographs for storage areas "K" and "S" that were analyzed in the Charles River NVS study. Area "S" shows very little change between its inflow and outflow curves. Therefore, this particular storage area does not exhibit very much natural storage capacity. Area "K", on the other hand, shows great changes between its inflow and outflow curves. This area appears to have significant storage capabilities.

While certain storage areas act like reservoirs in that they only store water, some also convey or move floodwater. This is called off-channel storage and is usually characteristic along streams or rivers. Once a river overflows into storage areas along its banks, the storage areas then become part of the expanded river channel. The storage area not only retains the water but also moves it along its way downstream. This can sometimes help reduce peak flood elevations in the immediate flooding area.

The type of storage, whether reservoir or off-channel, determines the method used in the hydrologic analysis of a storage area. The analysis of reservoir type storage first involves estimating the inflow hydrographs for water entering a particular storage area. An outlet-discharge relationship is then developed using field inspection, historic high water information, USGS gauge data, and Flood Insurance Studies as guides. Hydrographs are routed through the storage area using a flood hydrograph model. The resultant outflow information of the storage area is routed downstream to the damage area of concern. The model is considered calibrated if the computed hydrograph relates reasonably well with observed data from previous flood events. The effects of lost storage are computed by assuming the outflow is equal to inflow in the storage area and then computing the downstream results.

The analysis of off-channel type storage is evaluated differently. In this case detailed cross sectional data of the river and its floodplain are needed. This can sometimes be obtained from the backup information of Flood Insurance Studies. Hydrographs of the inflows and tributaries to the storage area are also needed. A one-dimensional unsteady flow model is then used to route the flood through the storage area. The model takes into account the storage areas' conveyance capacity and a water surface profile that is sloped. The model is calibrated in a similar manner to the reservoir method. Loss of storage effects are determined by running the model using modified cross sections of the storage area.

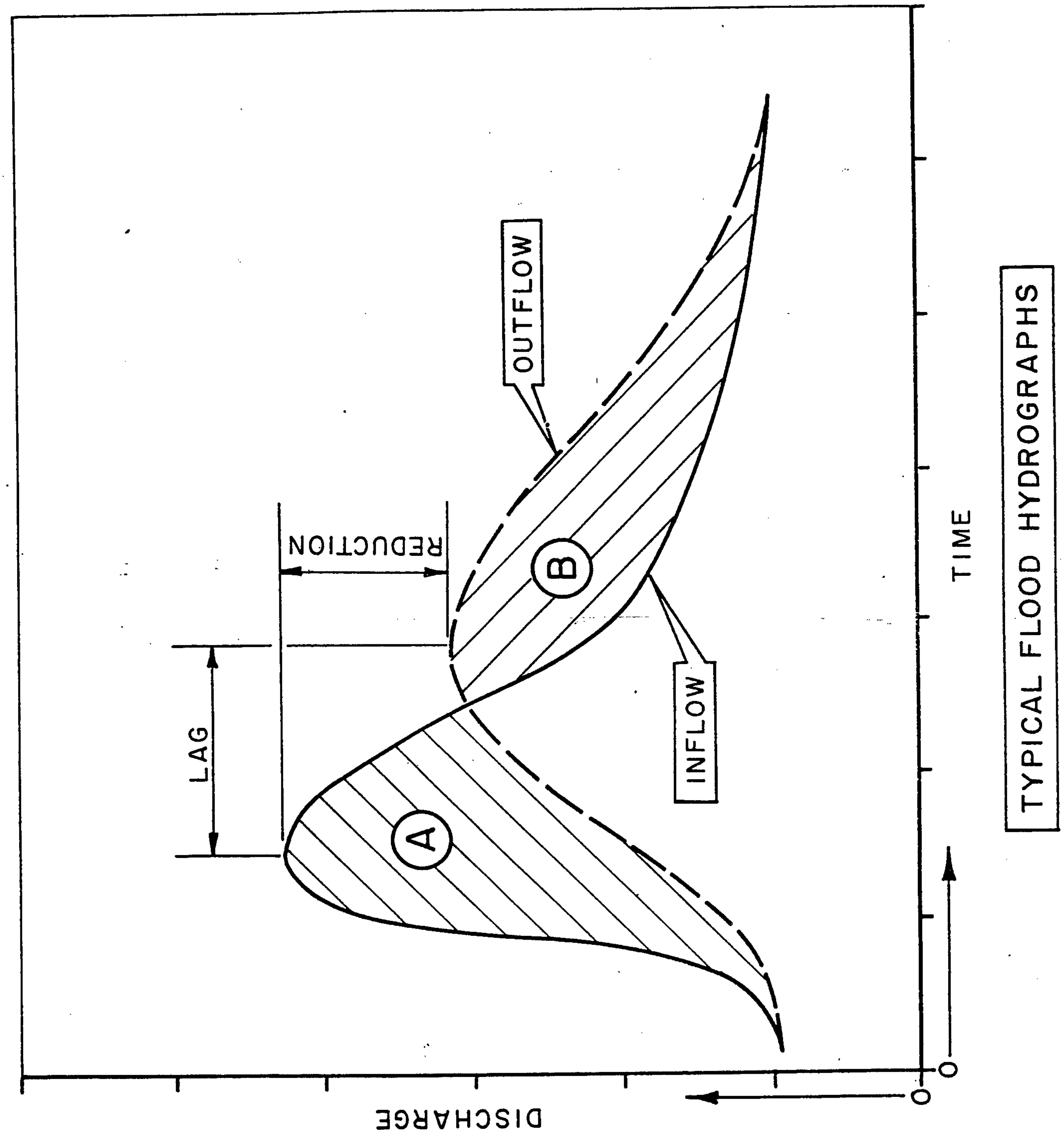
Often, an NVS analysis uses both of these methods of hydrologic analysis. A detailed explanation of the NVS hydrology and methods of analysis can be found in Appendix C.

**RUNOFF CHARACTERISTICS**

As mentioned before, the effectiveness of a particular storage area is dependent on several physical characteristics. A natural storage area's ability to retain runoff is related to soil type, slope of the storage area, and vegetation density.

Infiltration of runoff is a factor in natural storage. Different soil types are infiltrated by water in different ways. Sands, gravels, and organic soils are more likely to absorb water and are therefore more apt to be the basis for viable storage areas. Clay type soils do not transmit water well and are more likely to "shed" water quickly. Clay type soil would indicate a lower potential for natural storage.

The grade of a potential storage area is also a factor to be considered. If the surface of the storage area has a high gradient, when runoff occurs, storage will be minimal. The lower the gradient, the less chance floodwater will be conveyed from the site as runoff, and storage will be greater.


TYPICAL FLOOD HYDROGRAPHS
OUTFLOW
INFLOW
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DISCHARGE
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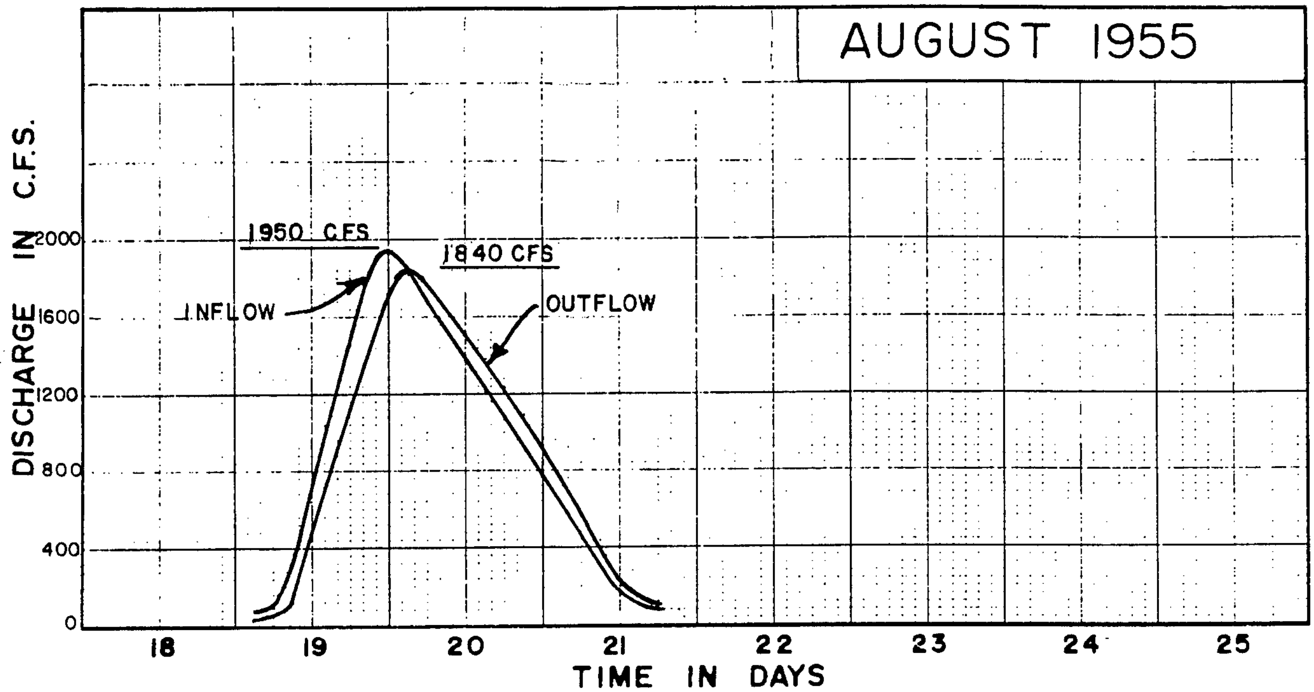
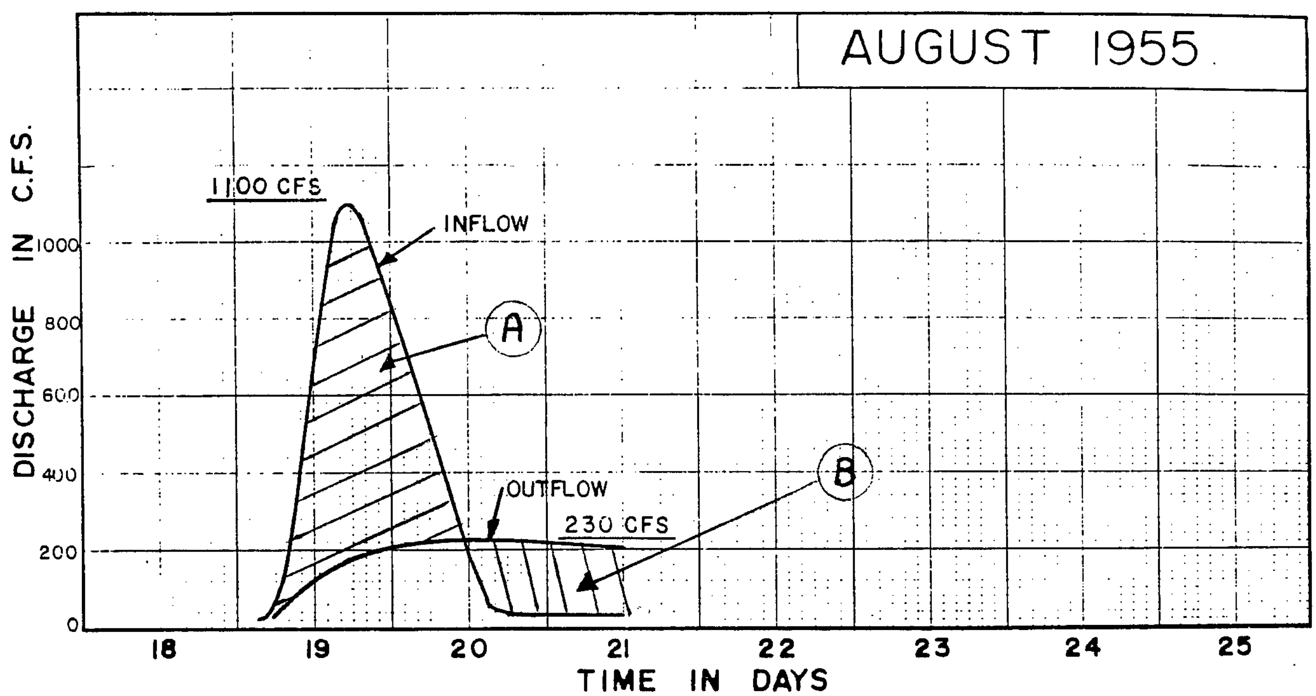
0

FIGURE 1




4 Inflow and outflow from storage area "S" during the 1955 flood from the Charles River Study.




Inflow and outflow from storage area "K" during the 1955 flood from the Charles River Study.

FIGURE 2

Vegetation can also affect a storage area's ability to contain floodwaters. Runoff is directly impacted by the roughness coefficient of the surface across which it flows. A surface covered with vegetation such as a wetland or forest will retard water's movement and serve to filter sediments and pollutants. A floodplain area devoid of vegetation will not retard flood waters as well. Development of these natural storage areas becomes even more critical as the natural vegetation is stripped and replaced with pavement. A paved surface offers very little frictional loss to runoff and subsequently has little storage capacity. Therefore, the altering of a natural storage area's gradient and development of the land for societal use can be very detrimental to a watershed's ability to naturally store flood waters.

## STORAGE AREA RELATIONSHIP TO WATERSHED

Within a watershed there are a network of brooks, streams, and rivers. These water bodies are often categorized according to their relationship within the watershed. First order (1st) streams are small, unbranched tributaries found in the upper reaches of a watershed. Second order (2nd) streams are larger and have only 1st order streams as tributaries. Third order (3rd) streams are larger still and have 1st and 2nd order streams as tributaries. A fourth order (4th) stream is sometimes the largest drainage stream in the watershed, however, the stream order may increase based on the size of the drainage system. The lower order streams have smaller drainage areas and so naturally are low flow tributaries. Conversely, the 3rd and 4th order streams are a cumulation of lower order streams, cover a larger drainage area, and convey higher flows.

Natural valley storage can occur throughout a watershed, but the location of the storage areas relative to downstream damage areas and to the total drainage area are important. The loss of a particular storage area along a 1st or 2nd order stream will probably not have a major impact on increasing flood flows at damage centers further downstream, because a lower order stream contributes only a small portion of the watershed's drainage. However, it would not be unreasonable to postulate that the cumulative loss of many small storage areas along the 1st and 2nd order streams of a watershed could have a greater effect on flood flows and flood elevations downstream. A single storage area along a 3rd or 4th order stream is more likely to have a major impact on a downstream damage center because of the larger drainage area and higher flows that pass through. Of course general statements of this kind are only that; each storage area must be evaluated on its own.

A prior Corps of Engineers' study of the Neponset River (1981) indicated that the loss of upper watershed storage areas had little effect on the downstream portions of the watershed. The Upper Neponset and East Branch Rivers contain 1,200 acres of surface area and provide 3,000 to 5,000 acre-feet of storage. The Fowl Meadow reach, further downstream, has 3,000 acres of surface area and provides 15,000 to 30,000 acre-feet of storage. The effects of losing the Neponset and East Branch storage areas were generally limited to the streams themselves. Fowl Meadow, a large storage area along the Neponset River, was determined to be able to absorb this loss and still protect downstream damage centers.

## IMPORTANCE OF NVS TO FLOOD CONTROL

As previously described, natural valley storage can and does play a significant role in flood control. The specific effect is very site specific and requires detailed analysis in order to be measured. The required analysis includes a determination of the size of the watershed, a determination of the total volume of unfilled floodplain, and an analysis of the hydrologic behavior of floodwaters under existing and reduced storage conditions. The loss of natural storage areas can threaten downstream areas with increased flood discharge and flood elevations and can increase flood stages in local or upstream areas. Sometimes the effect of storage loss is not as great as originally expected because new areas of natural storage are sometimes created with increased flood elevations; lessening the impact to downstream areas.

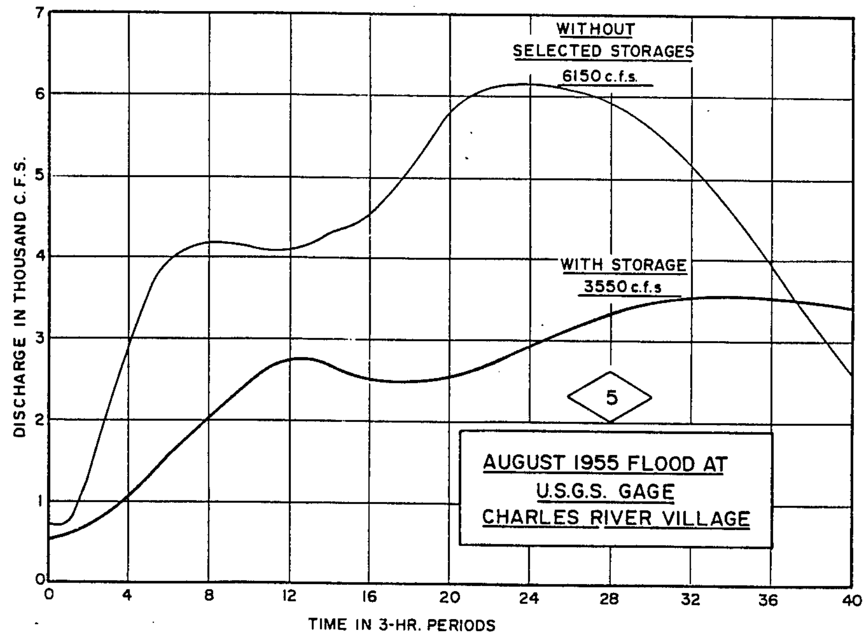
Flood magnitude and frequency play a role in the effectiveness of natural valley storage. During large volume, less frequent flooding, higher inundation along the fringes of the floodplain takes place. These areas are also the most likely storage lands to be lost to development because of less strict regulatory controls. More frequent flooding may not reach these fringe areas due to smaller flood volumes, discharges, and lower elevations. The effect of losing the fringe storage areas, therefore, may not be noticeable until the larger, less frequent flood events occur.

Natural valley storage is most effective in reducing flash-type flooding that peaks and recedes quickly, as opposed to long duration flooding when discharges remain high for a long period of time. Change in storage for a particular area occurs as a result of changes in elevation, which in turn is a function of change in flow. The magnitude of a change in storage area on outflow is, therefore, dependent on the rate of floodcrest rise, amount of floodplain area, and flow. During rising flood stages, outflow from a reach is less than inflow by an amount equal to the rate of rise in stage multiplied by the storage area. The amount of decrease between outflow and inflow peak is dependent on the nature of flooding. In a flash-type flood, the reduction of peak discharge approaches the difference between inflow and outflow experienced during the rising portion of an event. Long duration flooding is affected minimally by natural storage due to the fact that inflow equals outflow once the storage areas are filled to the stage required to sustain peak flow. Figure 3 shows graphically different hydrographs of the with and without storage condition for two different gauges from the Charles River study. Though not shown, a loss of storage and subsequent increase in discharge rates also translate into significant rises in flood elevations and greater flood damages.

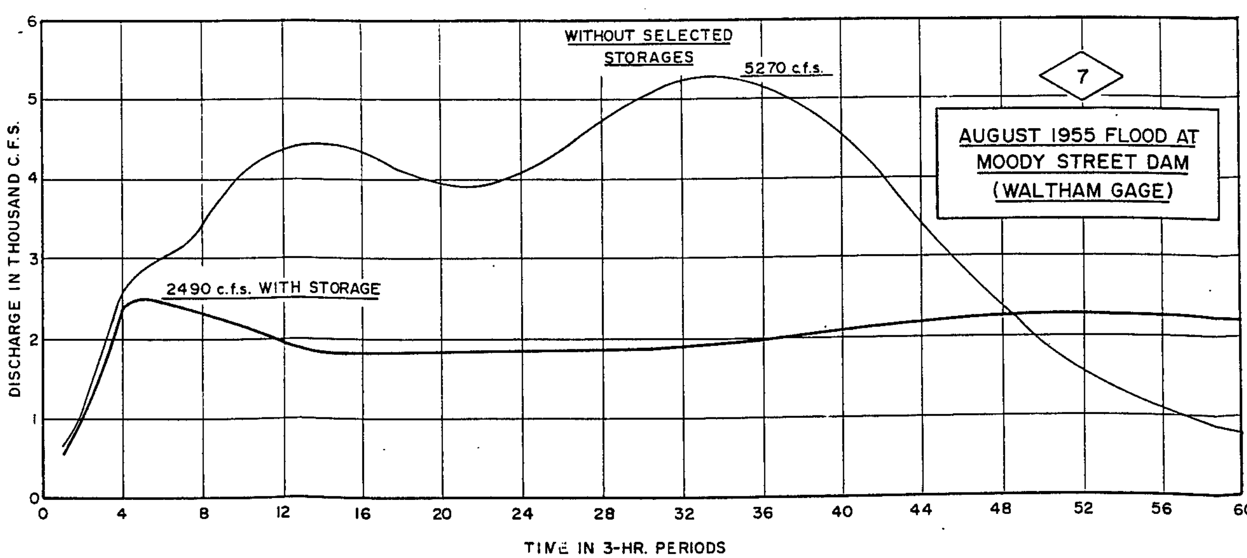
## OTHER VALUES

Natural valley storage areas not only provide nonstructural means of flood control, but several other potential values as well. Recreational opportunities often abound in these areas, including fishing, hunting, and hiking. This can result in the economic development of the surrounding areas, depending on the nature and scale of recreational usage. One of

the major reasons for such recreation use is the natural storage areas' attraction as a habitat for wildlife. Natural storage areas are often used for agricultural purposes or for the harvesting of other commercial products such as timber. Natural storage areas may also provide such things as educational opportunities, erosion control, water quality treatment, groundwater recharge, and may enhance surrounding property values. These and other natural storage attributes will be discussed in more detail later on in this report.




Hydrographs at the Charles River Village gage representing the 1955 flood with and without selected storage areas from the Charles River Study.




Hydrographs at the Waltham gage representing the 1955 flood with and without selected storage areas from the Charles River Study.

FIGURE 3

## 3. CHARLES RIVER FLOOD CONTROL PROJECT

**PROJECT SUMMARY**

The Charles River Flood Control Project is certainly one of the most successful as well as unique projects constructed and maintained by the Army Corps of Engineers. The project's authority originates in a resolution adopted 24 June 1965 by the House Committee on Public Works:

> "That the Board of Engineers for Rivers and Harbors is hereby requested to review the report on Land and Water Resources of the New England - New York Region printed in Senate Document numbered 14, 85th Congress, First Session, with particular reference to the Charles River Basin and tributaries, Massachusetts, with a view to determining the advisability of improvements in the interest of flood control, water supply, recreation, water quality control, navigation, tidal flood control, allied purposes, and related land resources."

A two phase study was conducted, the first of which began in 1967. The Interim Report on the Charles River For Flood Control and Navigation was completed in May of 1968. This study focused on the Lower Charles River, the most urbanized area in the basin and the area with the greatest need for flood protection. The second phase of study focused on the Charles River watershed as a whole. This study was completed in August 1972 and is entitled the Charles River Study.

The 1968 report recommended the construction of what is known today as the Charles River Dam Local Protection Project. The project is located on the Charles River between the North End section of Boston and Charlestown. The dam construction was initiated in 1972 with the removal of the Warren Street Bridge. Construction was completed in May of 1978 for a total cost of $61.3 million. The structure was built using a combination of fill and concrete construction. The dam is 400 feet long and its elevation is 12.5 feet above the National Geodetic Vertical Datum (NGVD). A pumping station which houses six pumps to control pool levels is also part of the project. Three locks were incorporated in the construction which allow recreation and commercial navigation traffic to pass through the dam. The two recreation locks are 200 feet long, 22 feet wide, and 8 feet deep. The commercial lock is 300 feet long, 40 feet wide, and 14 feet deep. The project also includes a boat facility for the Metropolitan District Commission (MDC), a small recreation park, a visitors center, and a fish ladder. The project provides flood protection, from both upland and ocean sources, for about 2,440 acres of property, worth an estimated $500 million. Since its completion the project has prevented an estimated $27.0 million in damage. The project is operated and maintained by the MDC.

The 1972 report recommended protecting natural valley storage areas in the Charles River Basin by having the Federal government purchase the land. The primary purpose of the project was flood damage reduction but secondary purposes of recreation, and fish and wildlife management (hiking, canoeing, fishing, hunting...) were also achieved. The project is known today as the Charles River Natural Valley Storage Project.

The Charles River is eighty miles long, winding its way from its headwaters in Hopkinton to its mouth in Boston Harbor. The Charles River watershed is 311 square miles in size, of which over 20,000 acres is swamp, marsh, and wet meadow. The watershed is divided into three basins: the lower, middle, and upper. The lower basin was the focus of the Charles River Dam project. The middle and upper basins were the focus of the natural valley storage project.

The Army Corps of Engineers began purchasing parcels of land for the project in May of 1977. The project was completed in September of 1983. Seventeen different areas have been purchased, totalling over 8,000 acres. The total cost of the purchases was $9 million dollars. The lands purchased are located in fifteen different communities. The purchased lands guarantee their continued use as storage areas against potentially damaging flood waters by protecting them from development. A map of the watershed and the location of project lands can be seen in Figure 4. The corresponding parcels by town and acreage can be seen in Table 2.

Table 2

Natural Valley Storage Areas

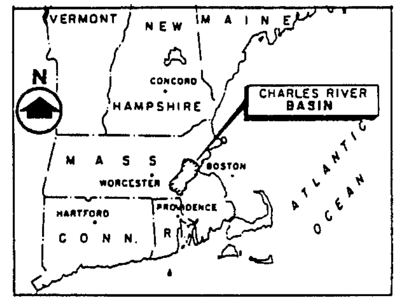
| Designation | Stream | Acreage | Communities |
|---|---|---|---|
| A | Charles River | 1,029 | Needham, Newton, Boston, Dedham |
| B | Trout Brook | 250 | Dover |
| C | Fuller Brook | 284 | Needham |
| D | Indian Brook | 234 | Natick, Sherborn |
| E | Sewall Brook | 118 | Sherborn |
| F | Charles & Stop Rivers | 2,340 | Norfolk, Sherborn, Medfield, Millis |
| G | Bogastow Brook | 907 | Medway, Millis |
| H | Trib. of Bogastow Brook | 280 | Sherborn |
| I | Dropping Brook | 130 | Sherborn, Holliston |
| J | Stop River | 395 | Norfolk |
| K | Mill River (not purchased) | 360 | Norfolk |
| L | Mine Brook | 395 | Franklin |
| M | Mine Brook | 150 | Franklin |
| N | Miscoe Brook | 266 | Franklin, Wrentham |
| O | Hopping Brook | 704 | Medway, Holliston |
| P | Stall Brook | 180 | Bellingham |
| Q | Charles River | 400 | Bellingham |

Two criteria were used to select the natural storage areas. The first criteria was the parcel's hydrologic performance, specifically during the March 1968 storm (the event of record). About 10,000 acres along the river were determined to be superior storage areas. The second criteria used was each parcel's size. Only parcels greater than 100 acres were considered for purchase, as it was determined that anything less would not be cost effective to pursue. The seventeen parcels act as a single reservoir broken into many pieces. They act as a unified system that holds back and "desynchronizes" flood waters "by routing them sequentially" from one area to the next. The identified natural storage areas control about 75% of the Charles River storage capacity.

## Charles River Basin

The Charles River Basin is located mostly in eastern Massachusetts and comprises an area of 311 square miles. It has a maximum width of 14.5 miles and a maximum length of 30 miles.

The basin covers parts of Middlesex, Suffolk, Norfolk, and Worcester Counties.




LOCATION MAP

SCALE IN MILES

25 0 25 50 75 100

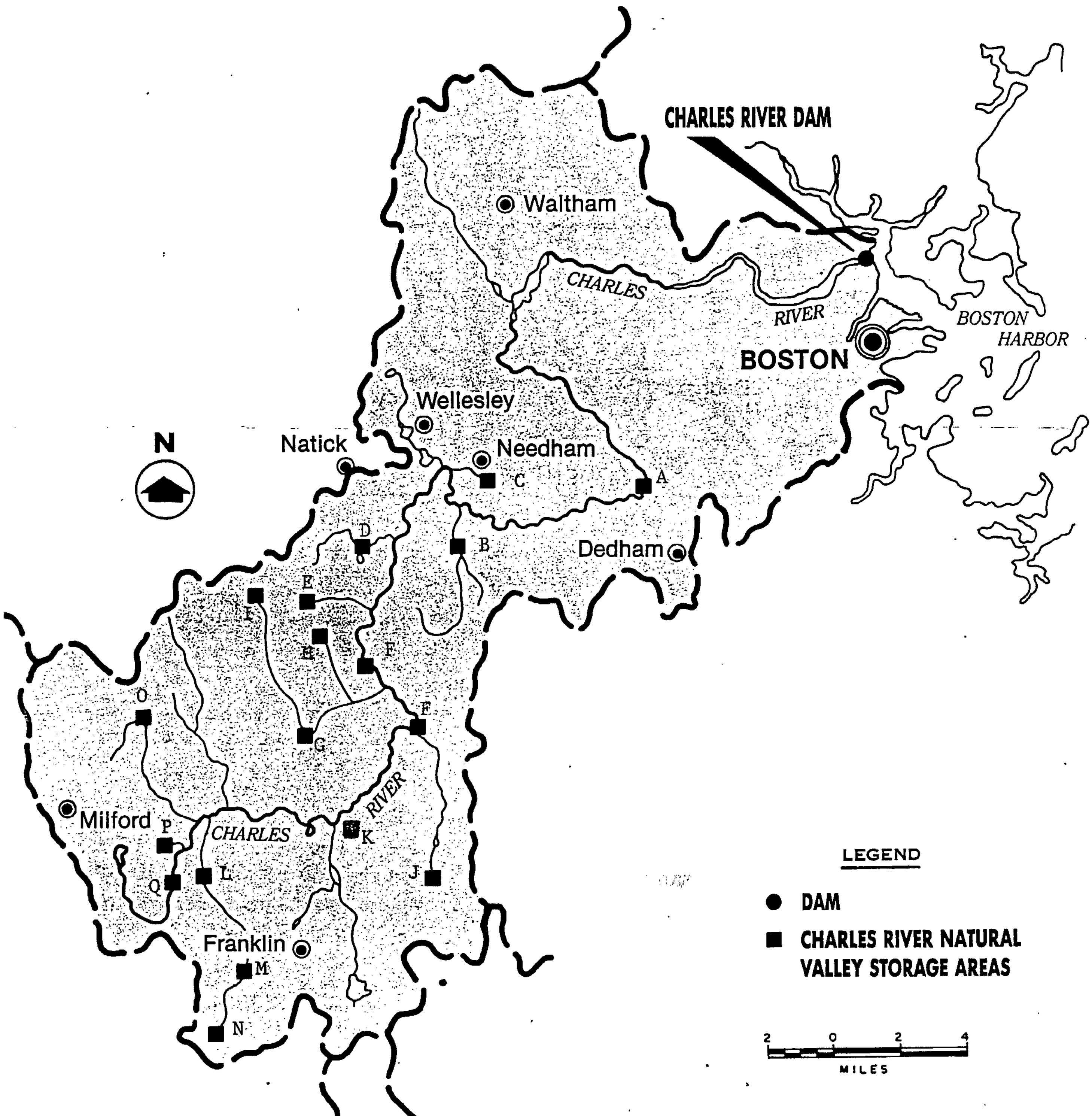



FIGURE 4

The project is one of the most successful uses of nonstructural flood control. The project is unique in that it avoids the more typical approach of using structures, and instead works with the natural characteristics of the watershed. The nonstructural solution was used instead of a structural solution which would likely have consisted of a 55,000 acre reservoir and elaborate system of walls and channels, which would have had high construction costs and environmental losses.

Each parcel was either purchased by fee or protected through easement; restricting building or filling. Purchase of the land offers complete control of its use while easements can provide savings of project costs. Existing utilities were allowed to stay in place through easement. Today the storage areas are managed by state, local, or private interests for flooding and wildlife purposes, with limited public access.

**BENEFIT/COST ANALYSIS USED IN NVS PROJECT**

In keeping with the engineering philosophy of many parcels acting as one reservoir, the economic justification of the project was conducted similarly. The benefit to cost analysis was not done on any one parcel, instead, the cost and benefits of the entire project were compared.

The costs of the project were based strictly on real estate acquisitions. The total first cost of the project was estimated to be $7,340,000 of which $7,000,000 was for real estate costs (purchase of land, easement costs, surveying, administrative fees, and contingencies). The remaining $340,000 was for engineering and design of the work. The annual costs of the work were determined based on an annual interest rate of 5 3/8 percent and were broken down as follows:

Table 3
Annual Charges From Charles River Study (100 year project life)

| | |
|---|---|
| Interest & Amortization ($7,340,000 x .054037) = | $397,000 |
| Operation & Maintenance | $ 80,000 |
| Total Annual Charges | $477,000 |

The benefits calculated for the natural valley storage project were based on categories of reduction of flood damages and the protection of ecological integrity. Other benefit categories mentioned, but not quantified were groundwater recharge, natural river flow during drought, aesthetic enjoyment, and, by being included in the National Wildlife Refuge System, superior waterfowl breeding and recreational use.

The acquisition of over 8,000 acres of wetland and floodplain reduces the chance of increases in flood damage due to the loss of natural storage areas. The flood level used in the benefit determination was four feet above the water levels experienced during the 1968 event. It was estimated that by the year 1990, 30% of the natural valley storage areas would be lost to development. This would result in an average annual equivalent increase in damages, above the present situation, of 34%. This translated into a $647,000 annual flood damage reduction benefit. These

were direct property losses to the urbanized areas of the Upper and Middle basins and not depreciated property values or rental rates due to repeated flooding.

The economic analysis also included an annual conservation benefit of $124,800. This benefit gain was broken down as follows:

Table 4
Ecological Benefits From Charles River Study

| | |
|---|---|
| Trout Stream Fisheries | $ 4,200 |
| Warm Water Fisheries | 7,500 |
| Wildlife Habitat - Wetlands | 38,800 |
| Wildlife Habitat - Water Fowl Hunting | 45,700 |
| Nature Study | 28,600 |
| | $124,800 |

The total annual benefits of the Charles River NVS project were calculated in the 1972 report to equal $771,800. This figure included $647,000 derived from the prevention of future flood damages if 30 percent of the natural storage in the basin were lost. The total $771,800 figure also included $124,800 in annual benefits attributable to environmental conservation. It should be noted that the ecological benefits were not accounted for separately in the economic analysis but were considered to be incidental to the primary purpose of the project, flood control.

The costs of a project are critical to determining whether the project is economically justified. Comparing the annual cost of $447,000 to the annual benefits of $771,800, the project had a benefit-cost ratio of 1.7, an economically justified project. Based on flood damage reduction benefits alone, the project was still justified with a benefit-cost ratio of 1.5.

## CORPS' POLICY AND REGULATION CHANGES SINCE 1972

At the time the Charles River study was being done, plan formulation was conducted under Water Resources regulations and policies very similar to today's. The overall theme of these regulations was to formulate plans of improvement that were based on the principle of promoting national economic development. Reports were to include an analysis of present and future expected economic conditions and the contribution the project would have on solving a problem and promoting future economic growth.

Based on these regulations, various types of benefits were allowed to be counted in the planning assessment. The first and foremost benefit category used in the justification of the Charles River project was the prevention of increased future flood damages. This included the prevention of flood damage to property, the loss of business, hazards to health and security, and any measurable returns due to a higher use of property resulting from prevented flooding. Recreation benefits allowed included increases in the quality and quantity of boating, swimming,

camping, picnicking, water sports, hiking, and sight-seeing. Fish and wildlife enhancement benefits were listed as a measure of increases in recreational resource preservation, and commercial aspects of fish and wildlife resources. In the absence of market prices for fish and wildlife benefits, a simulated value could be derived through the users' willingness to pay for the resource, costs actually being paid by users for a comparable opportunity, or another justifiable alternate cost.

Regulations at the time stated that the costs of water resource projects included the value of all lands, labor, and material used for constructing and maintaining a project.

Today, the regulations and policies remain essentially the same as those in effect at the time the Charles River Study was completed. However, the level of detail of these regulations has increased, providing greater explanation of how they should be applied to the analyses. However, the basic benefit and cost policies and guidelines remain unchanged.

**MAJOR FEATURES OF FAVORABLE CHARLES RIVER NVS PROJECT**

As was stated previously, there were several major features which contributed to the Charles River project's favorable economic analysis. The first, and most important feature in any Corps flood damage analysis, is the relationship between the stage-damage function in the basin and the stage-frequency function. The stage-damage function for a basin is determined through surveys of flood prone structures in the basin, and analysis of damages which could occur to those structures over a range of depths of flooding. The stage-frequency function is determined based on hydrologic data collected in the basin and through the application of hydrologic models. There is usually one stage-frequency function determined for existing conditions, and a second stage-frequency function determined for the proposed hydrologic change being analyzed, such as the construction of a reservoir or, in the case of natural valley storage, the possible future loss of basin storage capacity due to loss of wetlands or floodplains. The most significant determinant of the size of a proposed project's benefits is the relationship between the stage-damage function and the stage-frequency functions. In most cases the magnitude of project benefits are primarily a function of the degree it is determined that the proposed solution will reduce future flooding. If it is determined that the change in hydrologic conditions will be small between the with and without project conditions, then it is also unlikely that there will be significant benefits to the proposed project. Also, if there are not significant flood damages in a basin, then it is unlikely that there will be significant benefits to a proposed project. The Charles River NVS project was economically justified primarily because it fit both of the above criteria. First, the basin had significant damage centers and a history of flood damages, and second, it was determined that there would be a significant change in the hydrologic characteristics of the basin between the without and with project conditions. While one can examine variations in approaches, methodologies, and policies in performing analysis of natural valley projects, all of these factors are secondary to the hydrologic characteristics of the basin, the engineering

determinations made as to how those hydrologic conditions are expected to change in the future, and how a proposed project would impact these future hydrologic conditions.

Aside from the hydrologic characteristics of the Charles River Basin which were critical to the determination of the benefits of the project, a key assumption made in the 1972 Charles River analysis was the projection that, by 1990, there would be a 30 percent loss of wetlands in the basin. This projection was made based on the extremely high rate of growth that had been experienced in the suburban Boston area. There was a very large amount of support for this assumption contained in the report. The analysis was done at the time of the "urban flight" phenomenon, when large numbers of people were moving from the cities out to the suburbs, and at the time of the huge growth in the Route 128 industry belt. The growth in the area was unprecedented. The analysis was also conducted prior to the adoption of the Massachusetts Wetland Protection Act, regulations promulgated under Section 404 of the 1972 Clean Water Act, the National Flood Insurance Program, and Executive Order 11988. These regulations now give substantial Federal protection to wetland resources. In addition, data including aerial photographs were available which documented the degree to which wetlands were being filled. Hydrologic analyses and projections were determined to predict how the projected 30 percent loss in storage would affect the flood stages in the basin. The benefits to the project were determined to be the difference in the expected future annual flood damage losses if 30 percent of the storage were lost compared to flood losses if the storage areas were purchased and thus preserved.

Another important assumption made in the Charles River analysis was that the flood potential of the basin was projected to increase in the future based on an expected future growth in the value of the contents of the floodplain. As stated in the report, the projected increase in flood loss potential in the basin was based partly "due to additions to existing properties, part is due to increased values of contents in structures such as color television replacing black and white sets, and in a land poor area, part is due to new construction occupying every available piece of land. All these items are related to the increasing wealth in the area." (p. H-12, 1972 report) It should be noted that the projection of increased losses in the basin based on increased wealth and increased development in the basin came during a time of extreme developmental pressures in the area, and also during a time of significant real income growth.

## CHARLES RIVER NVS PROJECT COMPARED TO OTHER CORPS' STUDIES

The Charles River Project is the only successfully completed natural valley storage project in New England. However, several other studies have been conducted by the Corps of Engineers that investigated the use of this nonstructural means to reduce flood damages.

A study of the Spicket River basin, located in northeastern Massachusetts and southern New Hampshire, was completed in 1990. This study was a comprehensive flood damage reduction study, of which the examination of natural valley storage acquisition was only one of a large

number of both structural and nonstructural flood damage reduction measures examined. In the NVS analysis for the Spicket River study, as in the Charles River study, benefits to be attained from NVS acquisition were derived by comparing the difference between the expected future flood losses if the NVS locations in the basin were lost versus the expected future flood losses if the floodplains/wetlands were preserved through acquisition. The greater the amount of storage projected to be lost in the future, the greater the benefits that would result from preventing that loss through acquisition. For the Spicket River, the analysis was done for a range of possible future losses, including 10 percent loss of storage, 20 percent loss, 30 percent loss, 40 percent loss, and 50 percent loss. No definite projection for the future loss was actually made; all scenarios were examined, and under all of the possible future scenarios, acquisition of the storage areas was determined to be not economically justified.

The total annual benefits under the 50 percent loss scenario were determined to equal $134,000; the highest amount calculated in any of the scenarios. These benefits are the result of a complex relationship of factors including the existing level of flood losses in the basin, the hydrologic characteristics of the basin, and, most importantly, the hydrologic impact of a 50 percent loss in natural storage on the flood stages and flooding frequency in the basin. Since under this extreme scenario (50% loss of the storage areas is highly unlikely) the project was not economically justified, NVS as an alternative was not considered further.

Another important factor in the determination of the economic justification is the estimated cost of the acquisition. The cost of the lands to be acquired was estimated at $5,000 per acre. The determination of NVS acquisition costs, including the costs estimated in the Spicket River analysis, will be examined later in this report.

There were two types of benefits which were taken in the Charles River analysis which were not taken in the Spicket River analysis. First, there were no environmental benefits taken in the Spicket analysis. In the Charles River analysis, the environmental benefits made up 16 percent of the total benefits. It is important to note that the Charles River project would have been economically justified based on the flood damage reduction benefits alone. The Charles River analysis was done very early in the era of environmental awareness, and there were no established methodologies for claiming environmental benefits. Today, while there is much more environmental awareness and environmental enhancement is a benefit given much attention in the Corps, there is still a lack of generally accepted methodologies for quantifying environmental benefits. It was determined that even under the most extreme future loss of storage, 50 percent, the NVS alternative for the Spicket River was far from being economically justified based on flood damage reduction. It is likely that even with the inclusion of environmental benefits, if such benefits could have been quantified, the project would still have been not economically justified.

The second type of benefits which were not taken in the Spicket River analysis, but were taken in the Charles River analysis were the projection of a future increase in flood potential in the basin based on expected future growth in the value of the contents of the floodplain. The increases included, as described above in the summary of the Charles River analysis; additions to existing structures, new development, and increased value of contents of structures due to increased incomes. There was no such projected increase in future flood potential in the Spicket analysis. However, at the time of the Charles River analysis in 1972, many of the areas of the Charles River basin were under extreme developmental pressure and in fact the area has developed extensively. Additionally, it is likely true that the value of the existing development has also increased significantly over time, through additions, rehabilitations,and other such improvements. However, the period examined in the Charles River analysis was a period of extremely high and unprecedented growth. In contrast, by the time the Spicket River analysis was done in 1990, that period of high growth was past and significant regulations had passed restricting development in floodplains. Growth rates in New England have slowed significantly. Given the current economic climate in New England, a significant increase in flood damage potential is unlikely.

The Taunton River study was completed in 1978. In this study, like the Spicket River study, the natural valley storage option was just one of a number of flood damage reduction measures examined. The natural valley storage analysis in the report included the examination of a basin-wide natural storage acquisition project as well as the examination of several smaller parts of the basin. For the basin-wide NVS alternative, the report concluded that, "Basin-wide acquisition of the large swamps within the basin by the Federal Government is not economically justified due to the relative lack of downstream development and the high potential of flooding due to tidal influence." No explicit benefit or benefit figures were calculated for this alternative. A previous study, titled "Preservation of Natural Valley Storage in the Taunton River Basin", was prepared for the Corps by CME Associates in 1975. This study, which was referenced in the 1978 Corps report, concluded that: 1) under existing conditions of development and natural valley storage, flooding in the basin was not a severe problem; and 2) the existing regulatory and management programs are adequate to protect the storage areas if they are effectively managed.

Two smaller, localized areas were examined further for smaller-scale storage acquisition. The areas examined were specifically chosen as areas where there would more likely be higher benefits, in that the areas examined were located near the damage centers in the basin. The first area examined was the Salisbury Plain Brook area. However, the majority of the natural storage in this area was found to be already owned by the City of Brockton as part of D. W. Field Park. Since the storage area was already preserved through public (city) ownership, there was no economic benefit to Federal acquisition. The second area examined was the Mill River Basin. One large wetland area in the basin, of which 28 percent was contained in the Mill River basin, had, at the time of the report, just recently been purchased by the state of Massachusetts as a conservation

area. The Federal acquisition of another large wetland in the basin was examined. Using an estimated cost of $500 per acre for the acquisition of 700 acres, a total acquisition cost of $350,000, it was determined that the annual flood damages in the basin would have to increase by more than 50 percent in order to justify Federal acquisition. Based on the existing level of damages, the existing level of development, and the likely future development pressures, it was concluded that it was unreasonable to project an increase of 50 percent or more in future damages in the area due to loss of natural storage. Thus, it was concluded that Federal acquisition of natural storage in the Mill River Basin was not economically justified.

Overall, the reason none of the other NVS alternatives examined in the Taunton River study were justified was the overall low level of flood damages in the basin. Additionally, some of the existing flood damages were caused by tidal influences, which wouldn't be reduced by a NVS project, and thus could not contribute benefits toward justification of such a project. Also, important areas of natural storage in the basin near the damage centers were already publicly owned, making Federal acquisition unnecessary.

Finally, a floodplain management study of the Neponset River was completed in 1981 by the Corps of Engineers. One of the flood control alternatives considered was the purchase of natural valley storage areas. However, an economic analysis of this alternative was never conducted. Institutional analysis of the study area revealed regulations in place that, if enforced, would provide substantial protection of the natural storage areas.

In summary, several Corps of Engineers, New England Division investigations have examined the preservation of natural valley storage as a means to reducing flood damages. Natural valley storage investigations were conducted for the Charles River, Spicket River, Taunton River, and the Neponset River. The Charles River investigation resulted in the construction of the Charles River Dam and Charles River Natural Valley Storage projects. The NVS project was economically justified due to a combination of high projected loss of storage lands and the expected growth in the value of contents susceptible to flood damage. No structural or nonstructural flood control projects were undertaken as a result of the Spicket, Taunton, or Neponset river studies. In the case of the Spicket River, natural valley storage was not justified because the costs of preserving storage lands outweighed the flood damages prevented. In the case of the Taunton River, natural valley storage was not justified due to a lack of downstream damage areas, the fact that certain storage areas were already protected, and the existence of regulatory constraints that would make development difficult. In the case of the Neponset River, natural valley storage was not justified due to the existence of land use regulations that, if enforced, would prevent the natural storage areas from being developed

# 4. COSTS OF NATURAL VALLEY STORAGE

## METHODOLOGIES AND GUIDELINES

For a natural valley storage project in which the benefits are achieved through outright acquisition, the cost of the project is generally determined based on the market value of the land to be acquired. Other ways in which natural valley storage can be protected include the placement of easements on land, the placement of development (conservation) restrictions on land, and the use of tax or other incentives to induce private property owners to donate land for preservation. The costs of these other methods achieving NVS preservation could be much less than the cost of acquiring all of the property. The costs for these non-acquisition methods may include legal costs, administrative costs, and possibly tax revenues forgone if tax incentives are used to encourage land donations. While these non-acquisition preservation methods may have lower costs than acquisition, they also may have significantly lower effectiveness in preserving the natural valley storage. Their effectiveness may rest on the ability of the town or other public entity to enforce building restrictions, the success of the incentives to donate land, the political climate in the future, and possibly other unknown economic and political factors.

Corps of Engineers regulations concerning the determination of costs for Corps projects are contained in ER 1105-2-100, "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies". Sections of the regulation that are particularly relevant to estimating the costs of a NVS project are Sections 6-3, 6-4, and 6-141 through 6-144. These regulations are the guidance by which the costs for a Corps NVS acquisition project must be determined. In Section 6-144, the regulations state that, for acquisition projects, in addition to the Corps regulations contained in ER 1105-2-100, the requirements of Public Law 91-646, the "Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970", must also be followed. PL 91-646 defines the responsibilities of any Federal agency in acquiring real estate. The law was amended in 1987 with the "Uniform Relocation Act Amendments of 1987".

In general, ER 1105-2-100 requires that the costs of an acquisition project be based on the full fair market value of the real estate to be acquired. Additional costs incurred in the process of acquiring the property must also be included, such as legal costs, title transfer costs, and administrative costs. Section 6-144, paragraph h.1. states that acquisition costs include all costs of acquiring the land, water, and mineral rights required for installing, operating, maintaining, and replacing project measures. They include all expenditures incurred in acquiring land, water, and mineral rights, easements, leases, and rights-of-way. Such costs include the cost of the land, water, and mineral rights minus salvage value; the cost of surveys incident to a sale; legal fees and transfer costs; and severance payments. These costs are based on the current market values and the actual current costs incurred by the Federal entity for carrying out similar land, water, and

mineral rights acquisitions. The market value of easements is based on the difference in market value of land without the easement and with the easement.

In addition to the guidelines for real estate acquisition, ER 1105-2-100 contains general guidance for the analysis of costs in any Corps project being examined. The regulations require that all costs be compared at one common point in time and that costs be converted to annual equivalent values and spread over the period of analysis. For most Corps flood control projects, the period of analysis is usually 50 or 100 years.

PL 91-646 requires that, in any Federal or Federally funded project which includes acquisition of real property, the full fair market value of the property be paid to the property owner. The fair market value should be determined through appraisals. In addition, PL 91-646 allows relocation assistance payments to be made to any person or business displaced by a Federal or Federally funded project. Relocation assistance payments cover moving and related expenses, title and other legal costs of purchasing a replacement dwelling, and other relocation costs.

## EXAMPLES OF COST ANALYSES USED IN CORPS' INVESTIGATIONS

The cost analysis in the Charles River NVS study was based on a real estate analysis performed by the Real Estate Division of the New England Division (NED) of the Corps of Engineers. The real estate analysis was performed in accordance with PL 91-646 which requires that the full fair market value of any land to be acquired be used. The full fair market value was determined by NED's Real Estate Division based primarily on recent comparable sales. NED's Real Estate Division personnel also examined the areas to determine the physical characteristics of the areas and their uses, and also obtained information from local real estate brokers, appraisers, and assessors. The parcels of land to be acquired were examined individually and the market value of each was determined. In addition to the market value of the land, costs were added on to the total cost estimate for administrative costs, severance damages, boundary marking, contingencies, and engineering and design.

It was recognized in the cost analysis of the Charles River NVS study that some property owners may, in the actual implementation of the project, prefer to have an easement placed on their property instead of having their property be acquired outright. However, the cost of acquisition was used in the cost analysis since it was not possible to know which property owners would prefer easements until the actual acquisition process began.

In both the Taunton River and Spicket River analyses, the acquisition costs were estimated through the use of a general, per acre estimated market value of the land to be acquired. In the Taunton River NVS analysis, the acquisition cost of the wetlands was estimated at $500/acre (1978 price level). In the Spicket River NVS analysis, the acquisition cost of the wetlands was estimated at $5,000/acre (1990 price level). For comparison purposes, even though the Charles River NVS cost estimate was not derived through the use of one general, per acre cost estimate, the total cost estimate in the Charles River analysis divided by the number of

acres acquired yields a cost of approximately $870/acre (1972 price level). Comparing all three cost estimates in constant 1990 dollars, the cost estimates were $2,400/acre for the Charles River analysis, $880/acre for the Taunton River analysis, and $5,000/acre for the Spicket River analysis.

The scope of the Taunton and Spicket River analyses did not allow for the detailed, parcel by parcel real estate analysis that was used in the Charles River analysis. However, the underlying methodology for determining the NVS costs was the same in all three analyses, in that the cost estimates were based on estimated market values. The smaller scope of the NVS analyses in the Taunton and Spicket River reports was due to the fact that the overall scopes of the Taunton and Spicket River reports were very large and complex, and natural valley storage was just one of a large number of flood control alternatives examined. In the Charles River report, natural valley storage was the only focus of the report. As a result, the scopes of the NVS analyses in the Taunton and Spicket reports were much smaller than the very detailed scope in the Charles River analysis. This was a function of the original intent, purpose, and defined scope of each study, and should not reflect negatively on the Taunton and Spicket analyses.

Corps of Engineers guidelines are clear concerning the methodology to be used to determine real estate costs. The full, fair market value should be used, and the market value should be determined based on comparable sales data. While all Corps NVS analyses follow this same methodology, the level of detail may differ, due to time and funding constraints and the scope of the requested study. The most accurate NVS acquisition cost estimate is the result of a detailed and thorough real estate analysis of the property to be acquired and a detailed analysis of comparable sales in the area. The NVS cost analysis is most likely to be very detailed and thorough if the primary or only objective of the study is to examine the feasibility of a natural valley storage project. If the NVS analysis is just a small portion of a very large, complex study with multiple objectives, it is much more difficult to give the NVS analysis the same level of detail.

It should be noted that in some cases it can be difficult to determine the fair market value of parcels of land being examined in an NVS study, due to a lack of available comparable sales.

## ECONOMIC BENEFITS OF DEVELOPMENT

The prevention of development on existing natural retention areas can have several beneficial impacts, including reduced flood damages, increased recreational opportunities, and enhanced environmental quality. The other sections of this report address and examine these many benefits that can be achieved by preserving natural valley storage areas. However, in the interest of examining all possible impacts of preserving natural valley storage areas, it should be recognized that in some cases there may be some economic benefits brought by development which will be foregone if that development is prohibited. The economic benefits brought by development can include increased economic activity, higher incomes,

higher employment levels, and increased tax revenues, in addition to the benefits brought by the development itself, whether that be satisfying demands for housing, satisfying demands for new shopping areas, or satisfying a need for additional production facilities for goods. Such benefits may be lost if the development is prevented because of a natural valley storage project.

## 5. BENEFITS OF NATURAL VALLEY STORAGE

### CORPS' POLICIES AND PRACTICES FOR BENEFIT ANALYSIS

The current governing regulation under which flood control and other benefit analyses are made is Engineering Regulation (ER) 1105-2-100 dated 28 December 1990. This regulation is titled "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies". It is also known as the "Planning Guidance Notebook" and as "P & G". Particularly relevant sections of this regulation include Chapter 6, Sections I and IV. Additionally, policy guides have been written by the Corps of Engineers' Institute for Water Resources (IWR) to explain and expand upon the regulations. The following policy guides are applicable to flood control studies:

1. IWR Report 88-R-2, "National Economic Development Procedures Manual - Urban Flood Damage", March 1988.

2. IWR Report 91-R-10, "National Economic Development Procedures Manual - Urban Flood Damage - Volume II - Primer for Surveying Flood Damage for Residential Structures and Contents", October 1991.

3. IWR Report 91-R-11, "National Economic Development Procedures Manual - Overview Manual for Conducting National Economic Development Analysis", October 1991.

The basic framework of Corps of Engineers benefit analysis is the National Economic Development (NED) framework. NED benefits are defined as increases in the economic value of the goods and services that result directly from a project or, more simply, as increases in National wealth. A key element of the NED framework is that economic benefits are looked at from the national perspective, not from a local perspective. In comparing alternative projects, the project with the highest net NED benefits, which is feasible from an engineering standpoint, is environmentally sound, and is publicly acceptable, is identified as the NED plan.

Another fundamental framework of Corps benefit analysis is that all benefits and costs are compared in annual terms, or average annual equivalent values spread over the period of analysis. The use of annual benefits and annual costs is standard, traditional Corps policy. This method ensures that costs and benefits are consistently compared on an equal basis.

Another important concept in Corps project evaluation is the use of with and without project condition analysis. All Corps projects are evaluated for the with and without project conditions over the period of analysis, which is usually 50 or 100 years. The purpose of making a distinction between the with and without project conditions is to isolate the changes that are projected to occur as a result of a project, from the changes that would occur if the project were not undertaken. The benefits to a project are then determined by analyzing and attempting to value the differences between the without project condition and the with project condition.

The primary NED benefit category in flood damage reduction studies is inundation reduction benefits. Inundation reduction benefits equal flood damages that would occur without a Federal project, but that would be prevented with a Federal project, including physical losses, income losses, and emergency costs. The physical losses category includes a wide range of flood damages including damage to structures, loss of contents, damage to roads, damage to vehicles, damage to utilities, etc.. Usually, physical losses are the primary type of inundation reduction benefits. Other much less common but allowable benefit categories include location benefits, intensification benefits, and employment benefits. Location and intensification benefits are related to changes in land use to higher value uses that could occur with a flood damage reduction project. Employment benefits are generated by the actual construction of a project, but are only allowable in certain areas of high unemployment as defined by Corps of Engineers' regulations issued annually.

## BENEFIT VALUATION TECHNIQUES

The total economic value of a resource can be considered the sum of two principal components: personal use value and nonuse value (Turner, 1991, Munasinghe, 1992). Personal use value has two components: direct use value and indirect-use value. As stated earlier, many of these values, outside of flood control, are incidental and cannot be used as a primary purpose for justification of a Corps' project.

Direct use value is the value of products or services produced directly by a resource. Direct use values provided by wetlands/floodplains include:

- commercial fish and wildlife production
- commercial production of timber and other natural products (e.g. peat, biomass)
- consumptive recreation (e.g. fishing, hunting)
- non-consumptive recreation (e.g. hiking, nature photography)
- agriculture (cropland and grazing land)
- educational opportunities
- aesthetics

Indirect use value is the value of services provided indirectly by a resource. Indirect use values provided by wetlands/floodplains include various ecosystem-level functions such as:

- flood control (natural valley storage)
- habitat value
- water quality maintenance (nutrient, sediment, and pollutant removal, stream temperature control)
- groundwater recharge and water supply
- erosion control
- aquatic food chain support
- long-term carbon storage

Nonuse or "preservation" value is the value of a resource unrelated to any current direct or indirect use. Nonuse value has at least two

components: option value and existence value (note: various other components have also been postulated, see Munasinghe, 1991; Randall, 1991; Pearce and Turner, 1990).

Option value is the value of potential future direct or indirect use of a resource. Option value includes both the value of personal future use and future use by others (note: future use value by others is sometimes referred to as "bequest value"). Option value is essentially the willingness to pay (WTP) to preserve the option of future use of a resource, and is analogous to "option value" in the real estate or commodities markets.

Existence value is the intrinsic value placed on a resource simply because it exists. It is completely independent of any current or potential future direct or indirect human use. For example, knowledge that a rare plant exists may have value to an individual despite the fact that he/she may never see the plant or obtain any other benefit from its existence. Although less tangible than personal use value or option value, there is evidence that existence value is real, and can be significant (Pearce and Turner, 1990; Randall, 1991).

Various methods can be used to determine use and nonuse values of wetlands and floodplains. The following discussion will focus on describing various methodologies that can be used to evaluate the benefits of natural valley storage.

Flood Control

In calculating flood control benefits, the Corps of Engineers follows the methodology and guidelines that have been developed by the US Water Resources Council. These guidelines are followed by all Federal agencies involved in flood control projects, including the Department of the Interior, the Soil Conservation Service, and the Tennessee Valley Authority. Based on a review of associated literature made in this study, this methodology appears to be the only methodology for calculating flood control benefits. In a few instances, flood control benefits calculated by the Corps, for a particular site, were used by others to attempt to estimate flood control benefits for a different site. This required very broad assumptions to be made, and the resulting flood control evaluation likely had a low degree of accuracy.

The basis of any Corps flood control benefit analysis is the flood damage survey. In the flood damage survey, large amounts and a large variety of critical field information is collected. The first step in the damage survey process is to identify the study area. The 100-year floodplain is used, as a minimum, to define the study area and all structures located within the floodplain are included in the damage survey. Once the limits of the floodplain are identified, all of the structures in the floodplain are identified, counted, and categorized. Structures are generally categorized into one of four categories, either residential, commercial, industrial, or public. The next part of the

damage survey process is to determine the elevation of each structure in the floodplain. Obtaining accurate elevation data is crucial to the benefit analysis, because it is through the elevations that the damage survey data is matched with the hydrologic data to determine expected flood damages. Elevations are most accurately obtained using surveying equipment and known benchmarks.

The final part of the damage survey process is to estimate damages to the structures in the floodplain over a range of flood elevations. The range of elevations is usually expressed in one foot increments above and below the first floor elevation of the structure. Probable flood damages are estimated for the actual structure, the contents of the structure, and the grounds around the structure. Damages for each structure can be estimated through various means depending on the scope of the study. In general, local property owners are interviewed, and questions are asked to determine the value of building contents and the effects of any recent past flooding. This process is usually most difficult for industrial structures and much less difficult for residential structures. Residential structures often have much in common, and damage data collected in studies are often applicable to other locations. In contrast, most industrial structures are unique, have unique contents, and often involve a large variety of types of damages.

Once all of the required information is collected, the stage-damage function or functions for the study area can be determined. The stage-damage function shows the dollar amount of damages that would occur to the structures at various levels of flooding. One aggregated stage-damage function is determined for each hydrologic reach in the study area, representing all of the structures in the floodplain in that reach.

Usually, a hydrologic analysis of the basin is also performed concurrently with the stage-damage analysis. The hydrologic analysis includes a determination of the existing flood frequency conditions in the basin, and a projection of the future flood frequency conditions that would occur if a Corps project were constructed. These analyses result in the determination of stage-frequency curves for both the without and with project conditions. The stage-frequency curve relates flood stages, or elevations, with expected probabilities or frequencies of occurrence. In the case of natural valley storage, the projected future conditions would be what would occur if lands were not protected and the natural storage capacity were lost. It is the degree of change in the hydrologic conditions between the without and the with project condition, interacting with the values of the stage-damage function, which determine the magnitude of the flood damage reduction benefits to be achieved with a proposed project.

The stage damage curve is then combined with the stage-frequency curve in order to derive the damage-frequency curve. Using the damage-frequency curve, the Expected Annual Damages (EAD) of the flood zone can be calculated. EAD are defined as the expected value of flood losses in any given year. EAD are calculated by computing the area under the damage-frequency curve. The EAD value does not mean that that amount of damage will occur in any particular year, but means that, over a long

period of time, the average amount of damage will tend to approach that amount. The EAD figure represents the weighted probability of occurrence of the damage amounts at the range of flood stages.

Using the stage-frequency curves for both the without and with project conditions, the EAD for both conditions are calculated. The annual benefits to the project being examined equal the value of the difference between the EAD without the project and the EAD with the project.

Cost of Flood Insurance Premiums

Another benefit category to reducing flood damages could be savings in flood insurance costs. The Flood Insurance Administration, which is a component of the Federal Emergency Management Agency (FEMA), administers a nationwide flood insurance program called the National Flood Insurance Program (NFIP). Generally, if a community decides to participate in the NFIP, residents of the community who are located within the floodplain defined by FEMA are eligible to purchase insurance.

If a proposed project would result in some houses or other properties no longer being located in the 100-year floodplain through the reduction in expected flood flows, then there may be savings to those residents from no longer having to pay flood insurance premiums. The first step in calculating such benefits would be to determine if the community in question actually does participate in the NFIP, as not all eligible communities do participate. The second step would be to determine to what degree the proposed flood control project reduces flood flows and how the limits of the 100-year floodplain would be changed with the project. The next step would be to determine how many properties would no longer be in the 100-year floodplain with the project. Once the number of properties affected is known, the cost of flood insurance for each property affected, a cost that would no longer have to be paid if the project were implemented, could be counted as a benefit to the project. Analysts could either attempt to find out the actual cost of premiums paid for those structures or could use an average figure, depending on the study resources available. According to information obtained from FEMA, the flood insurance premium for a typical residential structure currently averages $350 per year.

In analyses performed by the Corps of Engineers, the complete premium cost cannot be counted as project benefits. This is because changes in the cost of premiums or the number of premiums paid are viewed by Corps policy as transfers between individuals or businesses, not as any change in the net income of the nation. In a Corps analysis, only the administrative costs incurred by the FIA on a per policy basis can be counted as project benefits. The amount of the average annual per policy administrative cost is published in the Corps of Engineers' Engineering Circular titled "Fiscal Year Reference Handbook". The current administrative cost to be used for flood control benefits is $79 per policy. The total benefits are determined by multiplying the number of properties that would be protected by the proposed flood damage reduction plan by the average annual administrative cost per policy.

## Institutional Costs of Increased Floodplain Development

There may be some institutional costs of allowing development on floodplains, costs that could be prevented through a natural valley storage preservation project. Specific institutional costs could include costs of a larger, more frequently needed flood insurance program than might otherwise be needed, costs of planning and implementing public safety programs, the costs of planning effective evacuation procedures, and the cost of response and recovery. However, actually quantifying the value of such institutional costs would likely be extremely difficult. The affected institutions, such as the Flood Insurance Administration, local police and fire departments, and regional emergency management and civil defense agencies, would most likely be in existence with or without a natural valley storage project. Attempting to determine the proportion by which their operating costs would be decreased (increase with no NVS) with a natural valley storage project would be very speculative.

## Enhanced Property Values

Another possible benefit category for a NVS project is the enhancement of property values for properties located adjacent to a NVS or areas created by the project. This benefit category assumes that properties, particularly residential properties, have higher values if they are located near NVS areas. Properties located near NVS areas may have higher property values than similar properties that are not, due to the benefits provided by the area, such as recreation opportunities and the esthetic benefits. In order to count enhanced property values as benefits toward a NVS project, the land use characteristics of the study area should be examined, and a real estate analysis of properties in the area should be performed. If the area has an abundance of natural areas, there may be no particular premium paid for properties near natural areas, and thus there may be no property value enhancements with an NVS project. If the area is predominantly urban or suburban, properties located adjacent to open space may have a significantly higher value than those surrounded by development, and thus there may be some property value enhancements with the project. This method of analysis is often referred to as the hedonic price method (HPM).

## Recreation

There are three widely accepted methodologies for estimating recreation benefits. The three methods are the unit day value method, the travel cost method, and the contingent value method. All three of these valuation methods are accepted for use by Federal water resource agencies, including the Corps of Engineers. These different valuation methodologies have evolved due to the nature of recreational goods in that recreational goods usually have no markets in the traditional economic sense, and thus there is usually no market price for the recreational goods being analyzed. If there were a market price, the recreational goods in question could be valued at the market price. The three recreational methodologies are different methods of attempting to determine a substitute for a market price in order to determine an economic value of the recreational goods.

The unit day value (UDV) method is the simplest of the three recreation valuation methods. With the UDV method, the expected annual usage of the recreational site must first be determined. If a proposed project is being evaluated, usage both without and with the proposed project must be estimated. With the UDV method, usage is evaluated based on user-days, which are the number of expected days of use by individual users. The usage estimates can be made either based on records of past use, through the use of recreational demand models, based on use estimates made by knowledgeable officials, or based on use records at similar sites. Once the expected usage is estimated, point values are then assigned to various characteristics of the recreational site. The assignment of the point values is made based on general guidelines developed by the Federal water resource agencies and using the good judgement and experience of the analyst. If the analysis is comparing a without and with project condition, various characteristics of the site might be enhanced with the project. The analyst must assign point values to reflect whatever changes might occur with the project. The characteristics evaluated with the UDV method are the overall number of activities available at the recreation site, the availability of similar recreation sites in the area, the carrying capacity of the site, the accessibility of the site, and the environmental and esthetic qualities of the site.

Once the user-day point values have been assigned, the point values are converted to dollar values based on a conversion table updated yearly by the Corps of Engineers. The resulting dollar value is the estimated value of the recreation experience available at the site for one user-day. This value is multiplied by the total annual usage estimate to yield the estimated annual dollar value of the recreational site.

The advantages of the UDV method are that it is relatively easy to use, can be used without extensive and costly user surveys, and is also thus relatively inexpensive to use. The disadvantages of the UDV method are that its use is dependent on the good judgement and experience of the analyst, the point and dollar values used are somewhat arbitrary, and the recreational values are not developed through a site-specific analysis.

The travel cost method (TCM) uses the expenditures made by site users in traveling to a recreational site as a way of estimating the value of the site to the users. With the travel cost method, as with the UDV method, the expected use of the recreational site must first be estimated. Once the usage for the site is estimated, the value of that use is then estimated using the travel costs incurred by users as a substitute for market prices.

Two components of travel cost are used to determine the total value of the travel cost. The two components used are the variable costs of operating an automobile the distance travelled to the site, and the value of the time used in the travel. The per mile variable costs of operating an automobile can be estimated directly, or can be obtained from the Department of Transportation or the Internal Revenue Service (IRS). Depending on the exact source or methodology used, current per mile

automobile operating costs have been estimated at $.20 to $.28 per mile. The value of the travel time is more difficult to estimate than the per mile vehicle costs. There has been and continues to be some disagreement among academics and analysts as to the proper way to value this time. One accepted method, and the method described in Corps of Engineers guidelines, is to value the time at one-third of the average manufacturing wage in the study area. Different analysts have presented arguments yielding time valuations ranging from 10 percent to 100 percent of the local average wage.

In general, a TCM analysis assumes that, at least to some degree, the frequency of use for different users will be related to the distance they must travel, and thus the travel costs they incur, to get to a recreational site. Users who live closer to the site will be more likely to use the site more often than those who live far from the site. The travel distance, travel time, and frequency of use data required for a TCM analysis must be collected through surveys or questionnaires of actual site users.

With the travel cost method, the relationship between the frequency of use relative to the travel distance is used to estimate a demand curve for the recreation site. This demand curve would use the calculated travel costs as a substitute for actual market prices. Total travel costs are calculated based on the travel data collected, the per mile vehicle operating costs, and the dollar value of the time spent traveling. The total value of the recreation use can then be estimated by calculating the area under this demand curve. Further, more detailed descriptions of the travel cost method, and more complete explanations of the economic theory behind demand curve analysis, are beyond the scope of this report. If more information or explanation is desired, please refer to the bibliography at the end of this report.

The primary characteristic of the contingent value method (CVM) is that, in a CVM analysis, the users are asked to actually estimate their own dollar valuations of the recreational site. The total dollar value of the recreational site is then calculated based on the actual user valuations. The user valuations required for a CVM analysis are obtained through direct questioning of actual site users, either through mail questionnaires, telephone interviews, or in-person, on-site interviews. The survey questions are typically quite extensive, and are designed in such a way that a hypothetical market for the recreational good is established. The users are then asked various buy, sell, or trade questions in order to estimate the value at which the user values the site. A set of example survey questions are: "Would you pay $3.00 per day to use this site? If yes, would you pay $4.00 per day? If yes, would you pay $5.00 per day?". These types of questions are repeated until the respondent says no. Then, the last value to which the respondent said yes is the value at which that respondent values the recreational site.

Like the other two valuation methods, the contingent value method also requires the expected usage of the site to be estimated. The total value of the recreation at the site is then estimated by multiplying the estimated usage by the dollar valuation determined by the contingent valuation survey.

Of the three recreational valuation methods, the contingent value method is in most cases the most difficult and costly method to use, primarily due to the difficulties and extensive time involved in designing, testing, and executing a successful CVM survey. Although the travel cost method also requires surveying site users, there are usually much fewer and much simpler questions in TCM survey compared to the questions required for a CVM survey.

Recreation-Induced Regional Economic Development

Recreation-induced regional economic development is a benefit category which may occur as the result of a natural valley storage project if the NVS project creates or preserves an NVS area which both is conducive to recreational use and successfully attracts such use. Assuming the NVS area is used or would be used for recreation, recreational users can bring economic stimulus to the area's economy as they purchase supplies, food, gasoline, and other goods at area retail establishments. These purchases increase the income of those businesses, helping the local economy. These expenditures then also work their way through the area's economy, as those businesses are then able to purchase more from other businesses, and then those businesses are able to purchase more, and so on. The net effect on the area's economy, known as the multiplier effect, will be an increase in the total income and employment of the region. The total contribution made by the recreational expenditures, including the multiplier effects, would equal the dollar value of the regional economic development benefits provided by the storage areas.

Before recreation-induced regional economic development benefits can be claimed, an analysis should be performed on the level of recreational demand and the levels and types of recreational use in the study area. If it is determined that there would be an increase in recreational use with a NVS project, than the amount of the increase should be estimated. Then, the amount of local expenditures typically made by users of the type of recreational resource involved should be estimated. This type of information can be found in local, regional, state, and sometimes Federal agency analyses and publications, although a significant amount of research effort may be involved. Once the typical expenditure figures are obtained, then this figure should be multiplied by the estimated increase in usage projected with the NVS project. The resulting value would be the total direct increase in expenditures in the local area that would occur with the project. Once the direct economic effects are determined, the multiplier effects must be estimated. This step involves primarily determining what the value of the economic multiplier is for the industries and region being examined. Determining the value of economic multipliers requires considerable expertise in regional economics. Once the value of the multiplier is determined, the total economic impact of the recreation on the region's economy can be estimated.

While regional economic development benefits can be significant and extremely important to local communities, Corps of Engineers regulations do not allow the use of regional benefits in Corps benefit-cost analyses. Corps guidelines require Corps analyses to look at all projects from a national perspective, not a regional perspective. Corps guidelines view regional effects as transfers from one region to another, not as increases in national income. Specifically, Corps guidelines would view the expenditures made by recreational users in one region as transfers from another region because, if the recreational resource was not available in the first region, the users would most likely spend the same in expenditures at a different recreational site in a second region. There would be a transfer in income from the first region to the second region, but there would be no change in national income. Corps guidelines require that only changes in national income can be counted as project benefits, and thus the Corps cannot include regional economic development benefits.

Educational Value

Educational value of natural resources has rarely, if ever, been quantified, but could be estimated using either the contingent value method or travel cost methods (see recreation section).

Water Quality

Water quality improvements induced by natural valley storage include settling of suspended material, and usually reductions in or storage of organics, nutrients, and metals. Both floodplains and wetlands promote settling of suspended solids due to their gentle slopes and low flow-through velocities. The slower the water movement and longer the hydraulic detention times of these storage areas, the more suspended materials settle, promoting higher quality waters downstream. Suspended sediments adsorb metals, nutrients, and organics, and these constituents may be temporarily immobilized or permanently lost when the sediments settle. The sediments sometimes resuspend during disturbances such as storms, or release the absorbed materials reintroducing them into the water. However, the accretion rate of sediments may prevent resuspension causing permanent immobilization. The amount of settling and rate of accretion is highly site and time specific, depending on hydrologic characteristics, soil types, topography, in-stream water quality, vegetation, etc.

A wetland can also improve water quality through biological and chemical processes in its soils and plants. Wetland sediments are usually anaerobic due to their continuously inundated state. Nitrification and denitrification processes in the water column remove most nitrogen from overlying waters. Plants take up nitrogen, and to a lesser degree, phosphorus, usually at significant rates during the growing season. However, a portion of these nutrients are released upon decay. Metal and organic contaminant loads of influent undergo change as they pass through wetlands as well. A wetland ecosystem may temporarily store, utilize, export, or transform these constituents due to its complex chemical and biochemical environment. A wetland that takes in or transforms constituents purifies the water as it passes through. On the other hand,

a wetland that exports more constituents than it takes in contributes to a poorer water quality effluent. A wetlands ability to act as a source or a sink depends on hydrologic characteristics, vegetation, sediments/soils, and microbiota (Elder, 1987).

Many studies have been conducted regarding the value of wetlands as nutrient sinks. Tilton et al. (1978) studied the role of wetlands in improving water quality and found nitrate and nitrite nitrogen, total dissolved phosphorus, and ammonium removals of 99, 95, and 71 percent, respectively. Furthermore, they found decreases in turbidity and suspended solids between inflow and discharge stations. German (1989) found a 36 percent decrease in nitrogen and 33 percent decrease in phosphorus by a natural wetland system. The Corps of Engineers Waterways Experiment Station compiled data from several wetland studies (some from Massachusetts) in the Northeastern United States and found cases where wetlands acted as sources, sinks, and transformers of nutrients and heavy metals depending on the particular wetland system.

Since many wetlands act as nutrient sinks, they have been successfully used to treat secondary effluent, storm water, and agricultural runoff. Removals of 60 to 90 percent suspended solids and 40 to 90 percent nitrogen from secondary effluent have been observed in various studies (Crites, 1988). Kadlec and Alvord (1989) demonstrate the Houghton Lake wetland treatment system in Michigan consistently treated over 400,000 cubic meters/yr of secondary municipal wastewater to 96 and 97 percent removals of total phosphorus and ammonium nitrogen, respectively, over an 11-year period.

One interesting feature of some natural valley storage areas is the riparian buffer strip. A buffer strip is usually a forested area along a stream's edge, on the order of 10-40 meters in width. These buffer strips have been found to be adequate in providing various riparian functions as it pertains to water quality. Shade from trees provides temperature control of the stream's water. They also have been shown to effectively reduce the amount of suspended sediments in surface runoff. Some studies indicate buffer strips have the capacity to remove sediments and certain nutrients and that the right size buffer strip can provide valuable habitat for plants and animals.

The replacement cost method (RCM) evaluates water quality benefits gained from natural valley storage by equating them with the cost of a replacement project, providing the same service to society. Water quality services that wetlands can perform include tertiary treatment of secondary effluent and treatment of storm water and/or agricultural runoff. Most reviewed literature focuses on wetlands, and it appears that few researchers investigated water quality benefits derived from non-wetland natural valley storage areas. Detailed studies have been conducted to determine a wetland's ability to assimilate nutrients, or perform tertiary treatment. The amount of nutrients removed or absorbed by a wetland is generally determined by comparing nutrient concentrations from inflow and outflow data.

Water quality benefits derived from the replacement cost technique are usually used with other techniques to provide an overall value of the natural valley storage area. Gosselink, among other researchers, incorporated replacement costs in a technique called energy analysis, which is a total resource approach for estimating a wetland's worth. It establishes the social value of the wetland in terms of the amount of energy it provides. For this analysis, Gosselink identified four groups of benefits for which dollar values were estimated, one group was sewage waste assimilation (Luzar and Gan, 1991).

Using this analysis, Gosselink determined that the per acre capitalized value of sewage waste assimilation performed in a particular wetland was $50,000 (1974 costs), based on the alternative cost of conventional tertiary treatment (Luzar and Gan, 1991). This was equivalent to an annualized cost of $3,000/acre. In 1973, Gosselink, Odum, and Pope converted sewage effluent loading results of phosphorus into an annual dollar value of $480 per acre by applying an alternative cost of $1.20 per pound of phosphorus removal by conventional methods (Park and Batie, 1979). Using this same technique, Bender and Correll converted their effluent loading results to an annual dollar value of $158 per acre of wetland for phosphorus removal (Park and Batie, 1979).

Luzar and Gan (1991) summarize, in detail, the limitations involved by using the replacement cost methodology (as part of the energy analysis), concluding that it tends to overestimate the value of wetlands by not considering factors such as human demand for natural system services. In other words, society must be willing to pay, at a minimum, the cost associated with the alternative method for the particular service (water quality improvement) the wetland provides (Park and Batie, 1979). If surface water discharge criteria requires only secondary treatment of wastewater, then a wetland receiving secondary discharge and functioning as a tertiary treatment facility may not be highly valued by the public for that function. Another significant limitation is that cost figures identified above are only reliable for the specific wetland studied, and cannot be generalized to apply to other wetlands or natural valley storage areas. Valuations are highly site specific, since the degree of sedimentation and assimilation of nutrients, organics, and metals varies greatly for each different natural valley storage area (Park and Batie, 1979). Extensive data collection at inflow and discharge stations would need to be performed to apportion water quality benefits incurred by each different storage area. Park and Batie (1979) identify another limitation warning that "only those wetlands plots that are actually used for nutrient assimilation have any value for that purpose." A wetland should not be valued as a tertiary treatment system if it is not being used as one. Finally, the replacement cost technique is limited by the complexity of wetland ecosystems, which are quite complicated and not entirely understood (Luzar and Gan, 1991).

The replacement cost method has been used to value water quality benefits of wetlands in other ways. Tilton et al. (1978) compared costs of nutrient removal from secondary wastewater effluent to tertiary levels using spray irrigation to the costs of treating the effluent using a wetland. Assuming 1978 prices, the discounted capital cost for a spray irrigation system was estimated to be $20,299 compared to $11,197 for

purchasing and maintaining treatment in a natural wetland. Limitations of this technique mirror those mentioned above, except Tilton evaluates a wetland's ability to assimilate waste even if it is not currently being used for that purpose. He assumes the wetland must be purchased, wastewater transported, and treatment system maintained to compare its value to other tertiary treatment facilities. Tilton mentions an additional concern regarding the use of existing wetlands to treat wastewater: regulations may prohibit the use of natural wetlands to treat secondary effluent.

Tilton et al. (1978) also suggest that the function of wetlands as natural storm water runoff collection and treatment systems could be considered in assessing a wetland's worth relative to the cost of collecting and treating storm water runoff by man made systems. When wetlands are filled, they no longer have the capacity to collect and treat storm water runoff. The runoff would have to be diverted to storm sewer pipes and rerouted to an alternative treatment site, for which Tilton estimated the 1978 discounted capital cost to be $9,237. This compares favorably to the no cost alternative of a wetland which collects and treats storm water runoff naturally. Besides diverting storm water runoff, land use practices can also be incorporated to reduce runoff from agricultural land to lessen sediment and nutrient loading to a waterway. Water quality improvement costs can be estimated by determining the net returns to farmers who apply these land use practices (Park and Batie, 1979). If a wetland treats secondary effluent along with runoff, the combined benefits give the wetland area even greater value.

A variation of the hedonic price method can also be used to estimate water quality benefits. It assumes people will pay for a wetland if it borders their property (between their property and the shoreline) provided it is aesthetically pleasing. The value of the wetland depends on physical characteristics such as setback, proximity, and aesthetic quality, as well as the local economy. Allen and Stevens present this methodology in their report entitled, "Use of Hedonic Price Technique to Evaluate Wetlands" (1983), stating that it "relies on observed behavior to value non-market goods." In other words, people would be willing to pay for this wetland to prevent it from being destroyed and, therefore, destroying their view. This methodology indirectly assesses the worth of a wetland's water quality benefits assuming that the cleaner a water is, the more people will value it.

Hedonic pricing tends to underestimate the value of certain wetland areas according to Allen and Stevens (1983) because of the following limitations. First, the proper economic model must be used to evaluate the area. Second, each evaluation is site specific, and cannot be generalized due to the great diversity in wetlands and local economies. Third, the home buyer and seller must be aware of the wetland area's value. Finally, certain externalities may fail to be incorporated into the house pricing market, such as a water fowl breeding area.

A third technique for determining the value of natural valley storage areas for maintaining water quality is the contingent value method. As discussed previously, this technique uses hypothetical willingness to pay

to protect a resource as a measure of the resource value. In this instance, individuals would be furnished with information concerning the role that wetlands/floodplains play in protecting water quality and asked to place a monetary value on these functions.

Erosion Control

Natural valley storage may improve downstream erosion control by attenuating peak floods, reducing the depth and velocity of the floodflow. Wetlands can sometimes reduce local erosion by sediment stabilization, wave energy dissipation and velocity reduction provided by vegetation. These attributes protect the adjacent shoreline or upland from erosion as well. One problem with assuming erosion control is a direct benefit of wetlands, however, is that most shoreline wetlands only develop and remain on shores with low wave energy and velocity where erosion is not usually a problem to begin with.

It appears that very little research regarding natural valley storage effects on erosion control has been performed. Owens (1980) conducted a study in Chesapeake Bay and found that the wetland vegetation and relatively flat configuration appear to dissipate incoming wave energy, protecting the shoreline located behind the wetlands.

Owens (1980) evaluated a wetlands worth as a means of erosion control to prevent flood damages in terms of the value of waterfront property. He found the value of a waterfront lot decreases as its erosion rate increases. He first determined the average income a person investing in a waterfront lot would receive over time. He states that "the value of income expected from a lot with a wetlands area lying in front of it was found to be higher than a lot without a wetlands area." Using this same methodology, Scodari (1990) suggests erosion control benefits can be valued based on the cost of removing sediment from a navigable waterway.

Limitations of this methodology are similar to those of the replacement cost method: it is highly site specific. In addition, Scodari (1990) states "it does not consider social preferences for wetland services or individuals' behavior in the absence of those services." If a wetland is altered, thereby eliminating its erosion control benefits, property owners may be willing to pay for a structural solution to prevent potential flood damages. In some cases, the cost of potential flood damages (incurred assuming the wetland is altered) may greatly exceed the cost of a structural solution. Consequently, damage cost methodology would overestimate the wetland's worth. Another major limitation is that this methodology only applies when altering (removing) the wetland is being proposed. If filling the wetland were the proposed alteration, erosion control of the adjacent upland would no longer be a concern.

As mentioned previously, the replacement cost method assumes the value of a wetland would be worth the cost of an alternative method of erosion control. Owens (1980) calculated the cost of bulkheading as an alternative and found naturally occurring wetlands to be a less expensive form of erosion control. This methodology could also be applied using other structural alternatives such as stone protection.

Replacement costs usually place a lower value on wetlands than the damage cost methodology. Major limitations of the replacement cost technology for erosion control are as follows: (a) it is highly site specific, and (b) it only applies if the wetland is going to be dredged and not filled in.

Groundwater

Natural valley storage can recharge groundwater provided optimum soil conditions and surficial geology prevail in the particular wetland or floodplain. Each natural valley storage area must be studied carefully to determine the soil and groundwater conditions indicating if the area recharges the groundwater or if the groundwater is discharging water to the surface. Groundwater recharge/discharge may vary seasonally, and water supply wells can also affect the recharge/discharge capacity of an aquifer depending on water usage. Aquifers studied in the Nashua River area were found to naturally discharge groundwater to adjacent streams. However, during periods of high use or "draw-down" the streams contributed some recharge to the acquifers (see case study). Groundwater recharge from wetlands is expected to be less than from other natural valley storage areas, as wetland soils are usually less permeable than soils associated with groundwater recharge (Larson, 1990).

The replacement cost method can be used if a wetland or floodplain recharges an aquifer that could be used for public or private water supply. It relates the loss of natural valley storage groundwater recharge benefits to the cost of a replacement water supply. Gupta and Foster used this technique to estimate groundwater recharge benefits for inland freshwater wetlands in Massachusetts during a study he conducted from 1973 to 1975 (Tilton et al. 1978). They determined the cost of pumping and delivering groundwater from a wetland aquifer compared to the cost of water supplied and delivered by a water purification plant in terms of dollars per acre. The difference in cost was $202.38 per acre (1972 costs), the net worth of the wetland as a groundwater supply source. Using the same approach, Larson (1976) estimated the annual water supply benefits of a typical inland wetland in Massachusetts, producing 1 million gallons per day (for water supply), to be $2,800 per acre (1972 costs). This estimate was based on studies of well fields located in the northeast United States having yields ranging from 300 to 1,400 gallons per minute and depths of 75 to 200 feet. It was also based on alternative water sources supplied and distributed by the Metropolitan District Commission.

Similar to other applications of replacement costs, one major limitation is that the estimates are site specific. In order to use this methodology to evaluate a particular natural valley storage area's groundwater recharge benefits, the area would have to be studied to determine if it recharges the groundwater and to what degree recharge occurs. Furthermore, the groundwater must be of high enough quality to serve as a water supply source. Another problem with using this method is that the public must need the benefits. In other words, if a groundwater aquifer is not

currently being used as a water supply, then society may not find its value to be equivalent to the cost of an alternative water supply.

The complete discussion on groundwater, as well as water quality and erosion control, benefits can be found in Appendix B.

Commercial Products

The simplest way to determine production value is by multiplying yield (i.e. annual production per acre) and the market price paid per unit of production. Costanza et al. (1987), for example, estimated the fur trapping value of Louisiana wetlands by multiplying yield of pelts per acre and the market price payed per pelt. Once the an annual production value is determined, capitalized wetland value can be obtained.

Although this method is straightforward, market revenues are not considered an adequate measure of resource value (Scodari, 1990). Resource valuation based solely on market price fails to account for consumer surplus (the excess of what consumers are willing to pay over actual price) and the costs of production (i.e labor and capital expenditures). A more appropriate measure of resource value is net willingness to pay (net WTP), the sum of consumer surplus and production surplus (i.e. gross earnings minus costs). Net WTP can be calculated using standard economic techniques, if sufficient information concerning market price, supply, demand, and production costs is available.

If adequate information is unavailable to estimate consumer surplus, an estimate of wetland or floodplain production value can be obtained simply by subtracting production costs from gross earnings. The resulting "profit" is used as a proxy for value, with average value per acre calculated by dividing net revenue by total acreage. This technique can be applied most easily to goods harvested directly from an area (e.g. pelts) but can also be applied to species which spend a critical part of their life cycle in one place, but are harvested elsewhere.

A more sophisticated method of valuing wetland or floodplain products is the marginal value product (MVP) method. This technique determines the value of an area for producing goods by estimating the change in output associated with a change in acreage (marginal productivity). The calculation of marginal productivity is complex, and involves use of bioeconomic models which relate production of goods to environmental variables and harvesting effort. Ultimately the value of wetland or floodplain input (per acre) to the production process is obtained. The MVP technique has been used to value wetlands for shrimp harvests in Louisiana (Costanza et. al. 1987), oysters in Virginia (Batie and Wilson, 1978), blue crabs on the Florida coast (Lynne et al., 1981), coastal fisheries in Florida (Bell, 1987), and fish in Saginaw Bay, Michigan (Amacher et al., 1989).

None of the above techniques considers the affect that commercial harvest of products may have on other land values. Harvest of timber or peat, for example, can substantially reduce land values for wildlife production and recreation.

Agriculture

The value of wetlands and floodplains for agriculture can be determined by using methods similar to those employed for commercial products. Market price and yield per acre can be used to provide an estimate of gross income. Net value can be determined by subtracting development costs (i.e. clearing and draining) and production costs from gross income.

Aesthetics

The contingent value method (CVM) is considered the best available technique for determining aesthetic value (see Graves, 1991). As discussed for calculation of recreational value, this technique determines willingness to pay by asking individuals to place a hypothetical market value on a resource. Two main approaches are used to conduct CVM studies (Luzar and Gan, 1991, Carson, 1991). In one approach, respondents are asked open-ended questions to determine WTP for a discrete action affecting an environmental resource (e.g. how much would you be willing to pay in taxes to protect one acre of wetland for wildlife habitat?). In the other approach, respondents are asked a series of yes-no questions in which the cost of the action is clearly specified (e.g. would you be willing to pay $100 to preserve one acre of wetlands?). Data is collected using personal interviews or questionnaires. For studies focusing on visual aesthetics, questions are typically asked in reference to a series of photographs or other visual representations of the resource.

Although the CVM technique is generally an accepted method for valuing nonmarket resources (and is sometimes the only method available), many questions remain concerning its validity (see Luzar and Gan, 1991). One key concern is simply whether or not people can accurately assess the monetary value of environmental resources. A second major concern is whether or not people's willingness to pay in a hypothetical market accurately reflects what they would pay in an actual market. Despite these limitations, results obtained in CVM studies are often reasonably close to those obtained using other methods (see Graves, 1991).

CVM studies must be carefully designed and administered. Results are quite sensitive to how studies are conducted and can be easily biased by a variety of factors (Luzar and Gan, 1991; Pearce and Turner, 1990). Results are particularly sensitive to the information provided during the survey. For example, because most people know little about wetlands, their valuation of wetlands in CVM studies is likely to be strongly influenced by the extent of information provided about wetland functions during the study. Additional information about the design and implementation of CVM studies is provided by Carson (1991) and U.S. Army Corps of Engineers (1986).

Hedonic methods can also be used to value aesthetics (e.g. Thibodeau and Otto, 1981). This approach determines resource value by measuring variation in property value (and often labor rates) associated with changes in resource attributes. To value aesthetics, changes in property

value would be related to distance from and changes in wetland and floodplain characteristics (e.g. size, vegetation type, amount of open space). Marginal WTP for each attribute is obtained using multiple regression analysis, with property value as the dependent value, and attributes as independent variables (Scodari, 1990). The technique is more difficult to apply than the CVM method and can be severely limited by lack of data, especially when land or labor markets in the study area are not well developed (Graves, 1991). Also, estimates of aesthetic value derived from the hedonic method probably include other values, particularly recreational value. Palmquist (1991) and Graves (1991) provide additional information about the hedonic technique and its use for valuing aesthetic resources.

It may be possible to determine aesthetic value indirectly from estimates of recreational value (Graves, 1991). This approach assumes that some proportion of recreation value is attributable to aesthetics (e.g. 40 % of the value of a canoeing experience is attributable to aesthetics, 30 % to fishing, etc.). Recreational value would be determined by any one of a number of methods (i.e. travel cost, contingent value) and a survey would be used to determine the proportion of recreation value people attribute to aesthetics. This techniques would ignore non-recreation based aesthetic values, such as affects on property value.

Habitat

Due to the land/water interface which is characteristic of natural valley storage areas, these lands often provide habitat for a surprisingly diverse number of species. Almost seventy percent of endangered and threatened species live in wetlands. Recent studies show that fish and aquatic animals are disappearing faster than land based fauna. Habitat loss accounts for much of the loss of these species. Riparian areas provide opportunities for biodiversity, and sites for foraging, hibernation, breeding, and nesting.

Habitat value for fish, wildlife, and plants can be determined using the contingent value method (CVM). As discussed for aesthetic resources, this technique determines willingness to pay by querying individuals as to the hypothetical market value they place on a resource. Data is collected using personal interviews or questionnaires. As discussed above, studies must be carefully designed and conducted to provide reliable results and minimize bias. The study should make a clear distinction between habitat value of an area for "ecological support" (an indirect use) and nonuse values (i.e. option and existence value).

Another measure used to estimate wildlife habitat value is societal payments to acquire and preserve conservation land. Gupta and Foster (1975) estimated WTP to protect wetlands for wildlife habitat in Massachusetts based on the purchase price and management costs of wetlands acquired by the state for conservation purposes. Wetland value was estimated using a three step process. First, a "base" statewide wetland value was determined from land purchase price and management costs.

Secondly, individual wetlands were evaluated ecologically using a 10 step habitat scoring procedure. Finally, wetlands which scored highly in terms of habitat quality were given a correspondingly higher percentage of the base wetland value. A key drawback of this method is that the purchase price payed by society for conservation land may reflect other values in addition to habitat value (e.g. recreational and aesthetic value).

Aquatic Food Chain Support

Riparian habitat can provide a substantial proportion of the energy available in stream ecosystems. For small streams, more than 90 percent of energy supporting in-stream food chains may be derived from detritus (leaves, fruits, wood) from adjacent riparian areas. The monetary value of this input has never been estimated. One approach might be to value the commercial and recreational fisheries output of the stream and assume that the proportion of this value attributable to the riparian zone is equal to the percent of in-stream energy contributed by riparian areas. For example if a stream's fishery has a value of $100 and the stream ecosystem receives 75 percent of its energy from riparian zone, the value of the riparian zone would be $75. This is a rather simplistic approach, and ignores the fact that shading by riparian vegetation reduces in-stream algal productivity.

Long-Term Carbon Storage

Peat deposits in some wetlands, particularly boreal peatlands, act as important global carbon sinks. This function may have monetary value if measures are needed to compensate for carbon added into the atmosphere by anthropogenic sources. One way to estimate the value of wetlands as carbon sinks is by the cost of sequestering carbon in other ways, such as by planting trees. Sedjo (1989) estimates that the cost of sequestering carbon in the U.S. by planting trees would be at least $172 per ton carbon sequestered. Based on this value, a New England bog sequestering carbon at a rate of about 0.6 ton/acre year (see Hemond, 1980) would have an annual value of about $100 per acre. Estimates of cost to avoid carbon emissions could also be used to indirectly determine wetland value as a carbon sink. For example, if the costs of avoiding carbon emissions is $50 per ton (Flavin, 1990), a wetland sequestering 0.60 tons/acre of carbon per year would have an annual value of about $30 per acre.

The above discussion focuses largely on non-forested wetlands. For forested woodlands, a similar value could be placed on carbon sequestration in above ground woody biomass.

Nonuse Value

The contingent value method is the only method available to determine nonuse values such as existence or option value. It has been applied to estimate nonuse value of a variety of natural resources, including wildlife, endangered species, wilderness areas, recreation, water quality, and seagrass beds (see Randall, 1991; Loomis and Walsh, 1986; Kahn and Kemp, 1985). A study of existence value of an endangered species, for example, might ask individuals to state how much she/he would be willing

to contribute yearly to assure continued existence of the species, or reduce the risk of extinction.

As previously discussed, results of contingent valuation studies are quite sensitive to study design and methodology, and can be biased by a variety of factors, especially the amount of information provided during the survey. More information about using the contingent value method to determine nonuse values is provided by Brookshire et al. (1983), Loomis and Walsh (1986), Pearse and Turner (1990), Stevens et al. (1991), and Randall (1991).

**TOTAL RESOURCE VALUE**

The total economic value of a wetland/floodplain can theoretically be calculated by summing all component use and nonuse values or by estimating total use value directly. Both approaches have shortcomings, and at present there is no clear agreement as to which is the best method. Several technical problems preclude simply determining total use value by summing component values (Randall, 1991). A major problem is potential double counting of resource values. For example, when summing recreational and aesthetic values, care is needed to assure that the aesthetic component of recreational value is not counted twice (i.e. part of the recreational value a canoeist places on a river derives from aesthetics). Summing component values to determine total value is also unlikely to be practicable in many cases due to the high cost of collecting the necessary data.

Several methods can provide a measure of total resource value. One approach is the contingent value method. As discussed elsewhere, this technique determines WTP by asking individuals to place a hypothetical market value on the resource. Reliance on the CVM method to determine total value seems unwise, however, given the availability of more precise techniques to value many important functions (e.g. flood control, recreation). The CVM technique is probably best employed only for determining specific wetland values that cannot be determined (or easily determined) in any other way (e.g. existence value).

A second approach that can be used to determine total resource value is the opportunity cost method. This method is based on the assumption that the value of a resource can be estimated from the income that is forgone in order to preserve the resource (Turner, 1990). For example, the value of a coastal wetland would be equal to the economic benefits forgone by preserving the wetland, rather than developing the site as an industrial park. A major problem with this technique is that wetland value is strongly dependent on the setting. Where alternative development options exist, benefits foregone may not be very large. On the other hand, in situations where development options are limited, benefits forgone may be very high. Ecologically similar wetlands in rural Massachusetts and suburban Boston, for example, would likely have very different values based on the opportunity cost method.

Another frequently suggested approach for determining total resource value is the replacement cost method. This method assumes the value of a

wetland is equal to the cost of constructing and maintaining an area of equivalent functional value. There are several problems with this technique. First, the underlying assumption that constructed wetlands can adequately replicate all natural wetland functions is still being studied. Secondly, the functional value of the existing wetland must be assessed to obtain design parameters for the hypothetical replacement wetland. While this may be relatively straightforward for some functions (e.g. wildlife habitat), for others (e.g. groundwater recharge) collecting the necessary data could be difficult and costly.

One measure of total wetland value is societal payments to acquire and preserve conservation land. Gupta and Foster (1975) used this approach to determine wildlife habitat value, but it may be more appropriate as a method for estimating total resource value. Wetland value would be established in a three step procedures. First, a "base" wetland value would be determined from land purchase price and management costs. Second, functional value of individual wetlands would be evaluated using a non-monetary wetland evaluation technique such as the Corps "Wetland Evaluation Technique" (U.S. Army Corps of Engineers, 1991). Finally, the individual wetlands would be given a percentage of "base" wetland value based on their relative functional value.

A radically different approach to valuing ecosystems is the energy analysis technique (see Farber and Costanza, 1987; Costanza et al., 1989). This method uses the total amount of energy captured by an ecosystem as an estimate of its potential to do useful work. The approach involves determining gross primary production of the ecosystem, converting this estimate to fossil fuel equivalents (FFEs), and converting FFEs into dollars based on the cost per unit of energy. This method should theoretically place an upper limit on the economic value of products produced by the ecosystem. It excludes, however, values not related to physical production such as aesthetics and existence value. The energy analysis technique has been strongly criticized, and its use has not been widely accepted (Luzar and Gan, 1991; Whigham and Brinson, 1990).

Most of the above techniques can, at least theoretically, provide a measure of total economic value. These estimates are best considered estimates of "gross" value, since preservation of these areas is not necessarily without cost. "Net" value should be determined by subtracting any management costs (e.g. construction and maintenance of facilities, mosquito control programs, law enforcement, and administration) from gross value. Table 5 graphically lists the various values and methodologies that have been described thus far.

T
Methodo

| | Damages or Costs Prevented | Unit Day Value | Travel Cost Method | Contingent Value Method | Replacement Cost Method | Hedon Me |
|---|---|---|---|---|---|---|
| Flood Control | X | | | | | |
| Flood Ins. Savings | X | | | | | |
| Enhanced Property Values | | | | | | |
| Recreation | | X | X | X | | |
| Recreation Induced Econ. Development | X | | | | | |
| Education | | | X | X | | |
| Water Quality | | | | X | X | |
| Erosion Control | X | | | | X | |
| Groundwater | | | | | X | |
| Commercial F&W, Timber, & other Natural Products | | | | | | |
| Agriculture | | | | | | |
| Aesthetics | | | | X | | |
| Habitat | | | | X | | |
| Acquatic Food Chain Support | | | | X | | |
| Long-Term Carbon Storage | | | | | X | |
| Non-Use Value | | | | X | | |
| Total Resource Value | | | | X | X | |

Footnote: Several methodologies may need to be employed in order to capture the total value of a particular storage area. Also, care should be taken to avoid the possible double counting of certain values.

Table 5
thodology Summary

| Hedonic Price Method | Market Revenues Method | Marginal Value Product (MVP) Method | Recreation Related Method | Opportunity Cost Method | Energy Analysis Technique | Past Pymts For Conservation Land |
|---|---|---|---|---|---|---|
| X | | | | | | |
| X | | | | | | |
| | X | X | | | | |
| | X | | | | | |
| X | | | | | | |
| | X | | | | | |
| | | | | X | X | X |

## 6. CASE STUDY

The following case study was conducted in order to demonstrate the methodologies available to quantify both the costs and benefits of preserving natural valley storage areas. The Corps of Engineers' economic analyses are required to be based on annualized costs and benefits. This was done everywhere possible in the case study. However, certain methodologies examined do not lend themselves to producing annual benefit values, but instead result in more of a gross value. This gross value was calculated where possible, but it should be understood that the gross values do not lend themselves to the traditional cost/benefit analysis and are used only in comparing relative worth.

Some of the methods highlighted require information that is either beyond the scope of this report or just not obtainable. For some of these methods that are beyond the scope of this study, information was included that outlines how one might go about measuring a certain value if the time and funding were available.

Also, due to the fact that the case study does not encompass the entire watershed, costs and benefits were calculated where possible and listed, but not compared. In a typical benefit/cost analysis a ratio of 1:1 or greater demonstrates a project's economic justification. The purpose of this case study is to demonstrate methodologies. Some of the benefit values are not comparable to others or are a source of potentially double counted benefits. Other benefit values calculated are incomplete, such as the flood damage reduction benefits, since only a portion of the watershed was able to be examined for flood control benefits. For these reasons a benefit/cost ratio was not sought.

### STUDY AREA

The area of study chosen for this demonstration was the Nashua River. The Nashua River begins at the confluence of the South Branch and North Nashua rivers in Lancaster, MA and runs in a northeasterly direction until it joins the Merrimack River in Nashua, NH. The Nashua River is approximately forty-one (41) miles long. The river was chosen for study because of the availability of flow data (due to the existence of several USGS gages in the watershed) and also because of the river's abundance of natural storage area.

The Nashua River watershed has a drainage area of about 538 square miles. Most of the watershed drains to the Nashua River, in a southeasterly direction, along several tributary rivers, the North Nashua, the Squannacook, and the Nissitissit rivers. Approximately 108 square miles of the South Branch River drainage area is regulated by Wachusett Reservoir. A review of the watershed, flood profiles, topographic mapping, and gage data was used to determine the location of the natural storage areas. The area with the greatest amount of natural storage is found between the confluence of the North Nashua River in Lancaster and East Pepperell, Massachusetts. There are additional storage areas dispersed throughout the watershed, though the areas are smaller in size.

Figure 5 shows the entire Nashua River watershed, including identified natural valley storage areas. The limited scope of this investigation made it necessary to focus our efforts on a reduced section of the watershed, in this case, the highlighted storage area located between Lancaster and Pepperell. A comprehensive study of the entire basin would be needed to fully understand the interdependence of all the resources and storage areas in the basin.

The natural valley storage area along the study reach has an area of 7.5 square miles (4,800 acres) and ranges in width from about 250 feet to one mile. The Nashua River has an average drop in elevation of about 1.5 feet per mile through the study area, and its flow is generally sluggish. The lower several miles of this reach is impounded by a dam in East Pepperell and is known as Pepperell Pond.

**LAND USE INVENTORY**

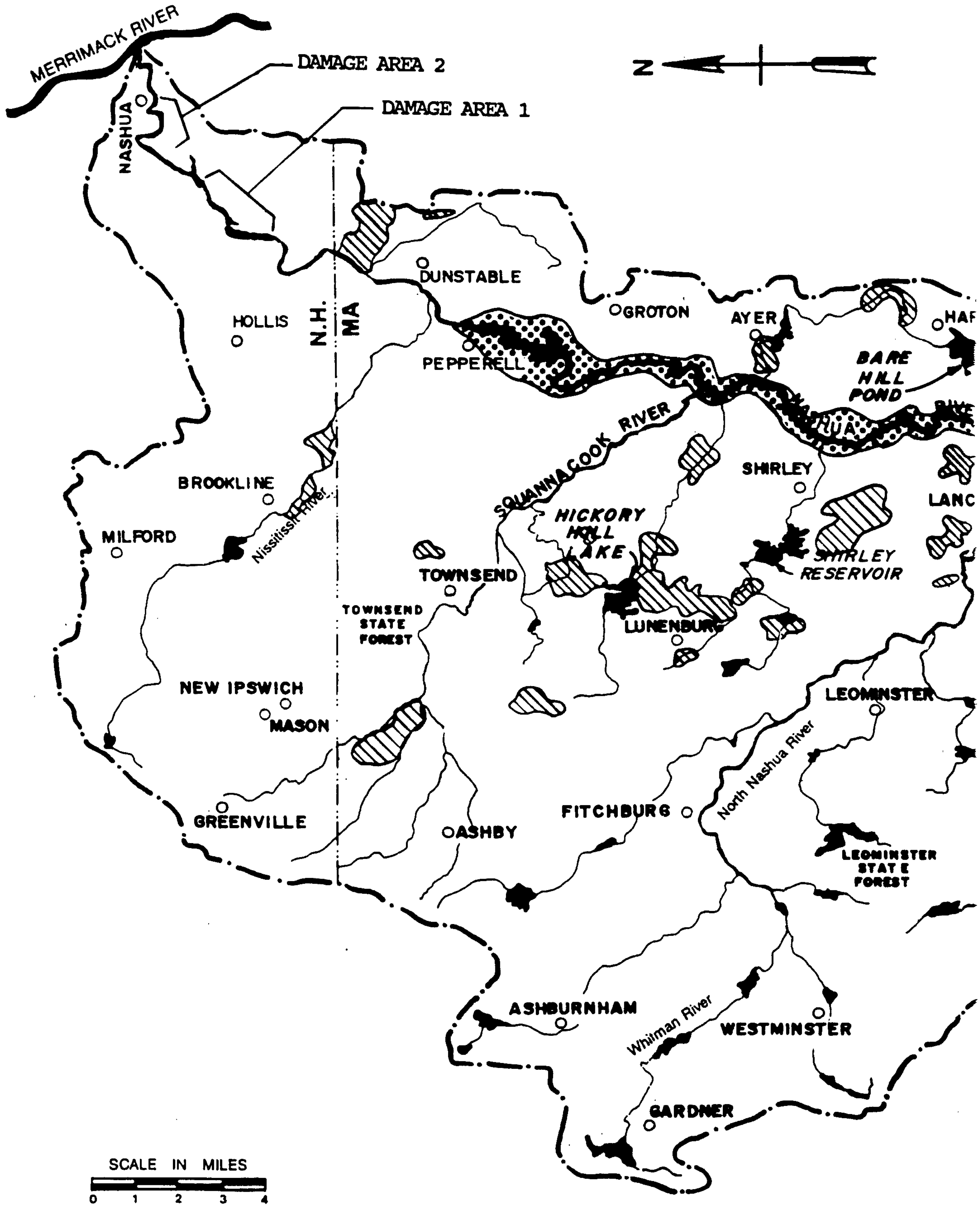
A very important part of any natural valley storage analysis is a complete inventory of the use and ownership of the lands in question. Without this information it is impossible to make reasonable assumptions of the future use of the lands which in turn will greatly affect any project formulation. A preliminary analysis of land use and ownership was made using information provided by the Nashua River Watershed Association, Open Space and Land Use/Cover maps provided by Massachusetts Department of Fisheries, Wildlife & Environmental Law Enforcement, and U.S. Fish & Wildlife Service National Wetland Inventory maps. The inventory is not completely accurate. That would require a detailed real estate analysis completed on a town by town basis. For the purposes of this case study an estimated or "rough cut" at the inventory was determined to be sufficient.

As mentioned earlier the storage area studied is about 7.5 square miles or 4,800 acres in size. Table 6 lists the types and percentages of land in this particular storage area.

Table 6
Nashua River Case Study - Land Inventory

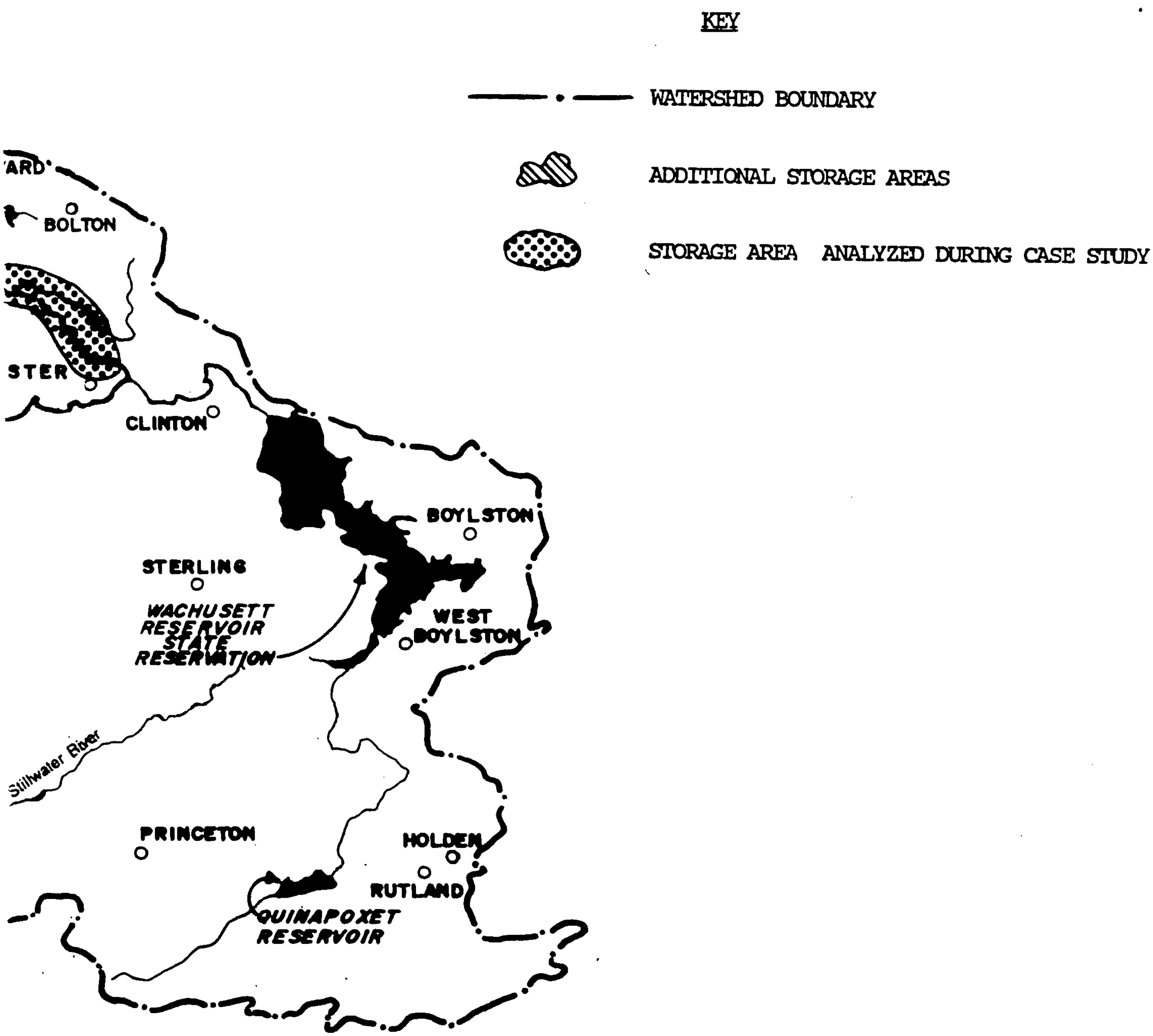
| Classification | Percentage of Total Storage Area | Total Acres |
|---|---|---|
| Upland | 58 | 2,780 |
| Riverine and Open Water | 14 | 670 |
| Emergent Wetland | 2 | 100 |
| Emergent/Scrub-shrub Wetland | 3 | 140 |
| Scrub-Shrub Wetland | 4 | 190 |
| Scrub-shrub/Forested Wetland | 4 | 190 |
| Forested Wetland | 15 | 720 |
| Other | 1 | 10 |
| Total | 100 | 4,800 |

Residential and commercial development within the storage area is very limited. That is because about 70% of the storage area, including the floodway (determined by Flood Insurance Studies), is strictly protected from development. Most of these protected areas are lands owned by




LOCATION MAP

(1)




MASSACHUSETTS NATURAL VALLEY STORAGE STUDY

**NASHUA RIVER CASE STUDY**

(2)

FIGURE 5

private organizations, towns, the Commonwealth, or the Federal Government. Some of the protected lands are also owned by individuals who have arranged to have conservation restrictions (CR's) placed on the property. Major conservation areas within the study area include the Bolton Flats Wildlife Management Area, Oxbow National Wildlife Refuge, the MCI-Shirley Greenway Trail, Groton Place, Sabine Lane, the Rich State Forest, and portions of the Fort Devens Army Base.

As shown in Table 6, 42% of the storage area is wetland. Forested and open water/riverine wetlands account for 80% of this total. The other 20% are emergent and scrub-shrub wetlands. The largest wetland tracts in the study area ( > 200 acres) are found in Rich State Forest, Oxbow National Wildlife Refuge, Fort Devens, and the Bolton Flats. The remaining 58% of the storage area is categorized as upland.

As previously mentioned, an estimated 70% of the study storage area is strictly protected from development. The other 30%, about 1440 acres, does not appear to be as restricted. Table 7 shows a breakdown of the types and amounts of land included in this 30%.

Table 7
Nashua River Case Study - Potentially Developable Lands

| Classification | Percentage of Total Storage Area | Total Acres |
|---|---|---|
| Forest | 15 | 720 |
| Cropland | 11 | 528 |
| Abandoned Open Space | 2 | 96 |
| Non-forested Wetland | 2 | 96 |
| Total | 30 | 1,440 |

Technically, these lands should all be protected by the Massachusetts Wetlands Protection Act, and to a certain extent by Federal regulations, as they are all subject to flooding. However, for the purpose of this case study it was assumed that these 30% will be the maximum amount of potential future lands lost to development. The difference between these lands and the other 70% is that the latter, on a first look basis, are designated floodway, greenway, or conservation areas that are by law impossible to develop or would require action under Article 97 of the Massachusetts Constitution to overturn their protected status.

As was described previously, flood magnitude and frequency are closely related to natural valley storage. During large volume, less frequent flooding, higher inundation along the fringes of the floodplain takes place. These areas are also the most likely storage lands to be lost to development because of less strict regulatory controls. More frequent flooding may not reach these fringe areas due to smaller flood volumes, discharges, and lower elevations.

In the following case study no attempt was made to differentiate between the high and low frequency inundation areas. In fact, benefits to recreation, water quality, erosion control, groundwater, and commercial products are more likely to occur in the lower, more frequently inundated storage areas. However, these same areas are included in the 70% of the storage lands described as strictly protected. It is in the higher, less frequently inundated areas, the remaining 30%, where benefits to protection against development are to be realized. In order to demonstrate the calculation of some of these benefit categories, separation of the fringe from the inner storage was not made. A more detailed analysis would require the linkage of lands protected to actual benefits realized.

## WATER RESOURCES

Research revealed some general information on aquifers in the case study area. A USGS Water Resources Investigation Report (90-4144) dated 1992, states that two potentially high yield aquifers lie near the Nashua River at Catacoonmaug Brook in Shirley and the Still River in Bolton (see Figure 6). These aquifers are sand and gravel deposits located in low-lying areas adjacent to surface-waters. These aquifers are capable of yielding 100 gallons per minute to single wells. Another USGS report entitled "Stream-Aquifer Relations and Yield of Stratified Drift Aquifers in the Nashua River Basin, Massachusetts" discusses the potential for recharge of groundwater by surface water under certain conditions. According to this report, the aquifers studied, naturally discharge groundwater to their adjacent streams. However, during periods of high well use, the streams actually contributed some recharge to the aquifer.

Public water supplies in the Nashua River watershed consist of groundwater wells and surface water reservoirs, the largest of which is the Wachusett Reservoir. Basin wide, only 17% of the public water supply is from groundwater; the rest is from surface waters. Of the estimated 48.3 millions gallons per day (MGD) publicly supplied in the basin, only 27.9 MGD is from the Nashua watershed itself. The rest is from other watersheds and is diverted to the Wachusett Reservoir located in the Nashua River Basin. A Massachusetts Department of Environmental Management (MDEM) report entitled "Nashua River Basin: Inventory and Analysis of Current and Projected Water Use" lists all of the municipal water supply sources and their 1986 pumping capacities. From this list, 16 municipal water supplies and no surface water reservoirs are located in or near the studied NVS areas. These water supplies are listed in Table 8 and a map showing their location is shown in Figure 7. Funding and time limited the research to municipal water supplies; the above information does not include condominium, restaurant, or private water systems.

Table 8
Municipal Public Water Supplies
Located in the Nashua River Study Area

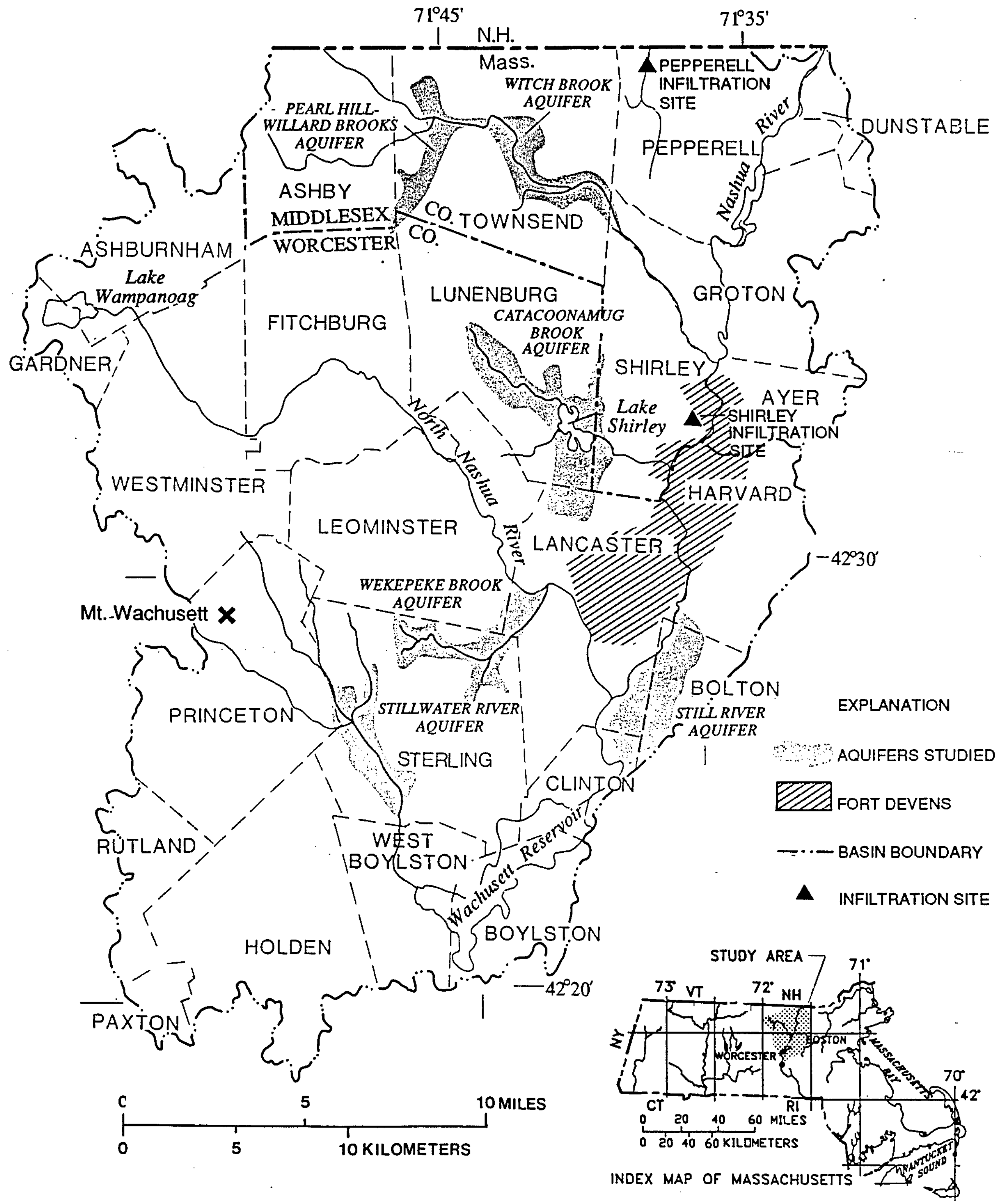
| COMMUNITY | PUBLIC WATER SUPPLY | DEP SOURCE NO. |
|---|---|---|
| Ayer | GP Well #1, Grove Pond | 2019000-01G |
| | GP Well #2, Grove Pond | 2019000-02G |
| Ayer-Fort Devens | Grove Pond Well System | 2019001-01S |
| | McPherson Well | 2019001-03G |
| Groton | TW, Townsend Road | 2115001-01G |
| Harvard | Rock Well, Pond Road | 2125000-01G |
| | Rock Well, Reservoir/Bolton Road | 2125000-02G |
| Harvard - Fort Devens | GP Well, Patton | 2019001-01G |
| | GP Well, Shabokin | 2019001-02G |
| Lancaster | GP Well #1, Bolton Station Road | 2147000-01G |
| | GP Well #2, Bolton Station Road | 2147000-02G |
| Pepperell | GP Well, Bemis Street | 2232000-01G |
| | GP Well, Jersey Street | 2232000-02G |
| Shirley | Samson Dug Well | 2270000-01G |
| | GP Well, Catecunemaug Road | 2270000-02G |
| | GP Well, Patterson Road | 2270000-03G |
| Dunstable | no wells in Nashua River basin | |
| Bolton | no wells in Nashua River basin | |

NOTE: GP - Gravel Packed
TW - Tubular Well

A limited search of point discharge sources revealed 25 industries and 7 municipalities that have been permitted by MDEP to discharge wastewater to the waters of the Nashua River Watershed. These point discharge sources are listed in Table 9. Only 8 permitted discharge points are located directly on the main stem of the Nashua River, four of which are municipal in nature.

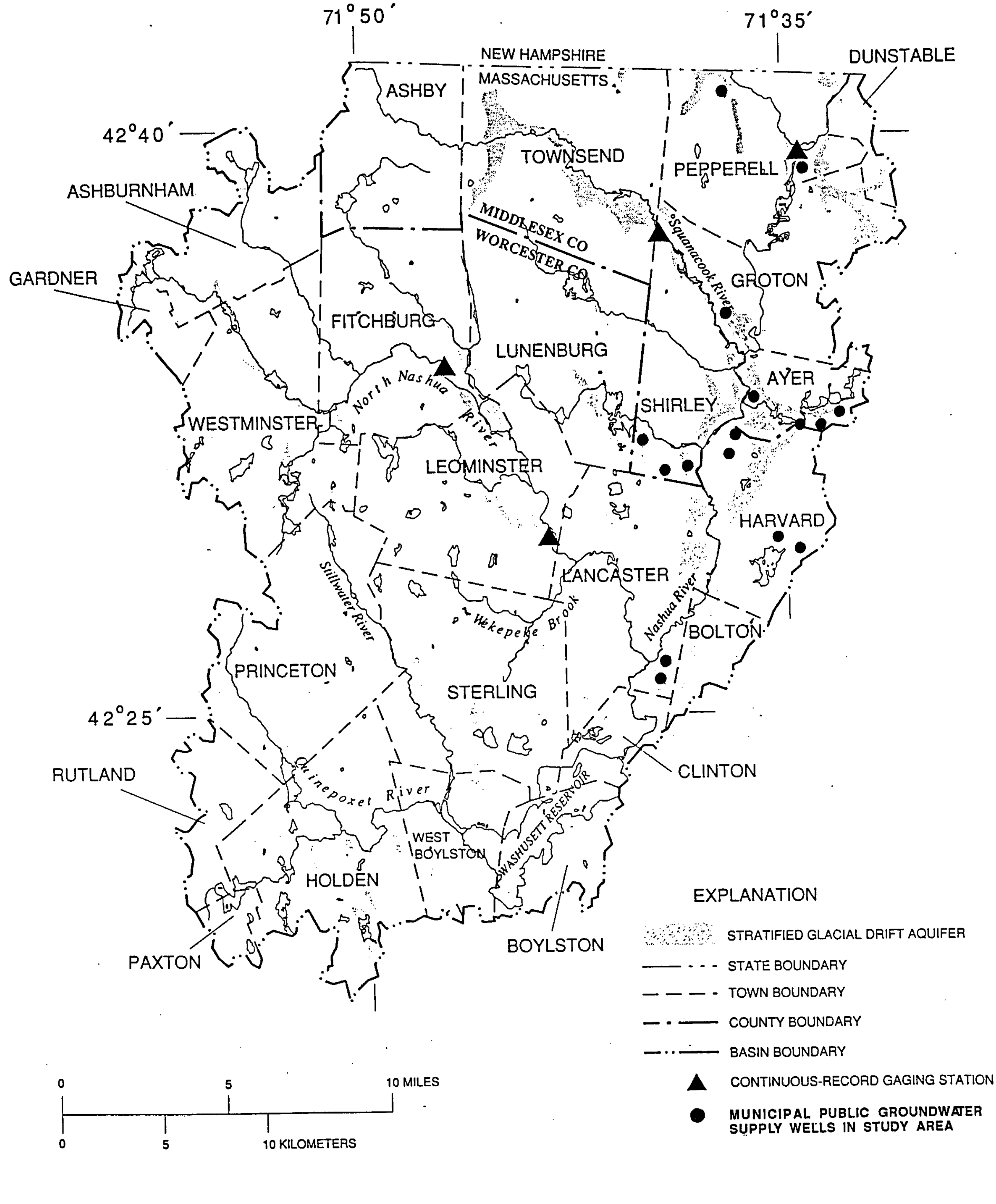
Table 9
Inventory of Wastewater Discharess

| | INDUSTRY/MUNICIPALITY | RECEIVING STREAM | COMMUNITY |
|---|---|---|---|
| 1. | Advance Coatings Co. | Snows Mill Pond tributary | Westminster |
| 2. | Alden Research Laboratory | Chaffins Brook | Holden |
| 3. | Ayer WWTP | Nashua River | Ayer |
| 4. | Berkey Film Processing | Baker Brook | Fitchburg |
| 5. | Cushing Academy | Phillips Brook | Ashburnham |
| 6. | Delta Supr.Wire & Cable | Counter Pane Brook | Clinton |
| 7. | ECC Corp. | Asnebumskit Brook | Holden |
| 8. | Fitchburg East WWTP | North Nashua River | Fitchburg |
| 9. | Fitchburg West WWTP | North Nashua River | Fitchburg |
| 10. | Foster Grant Co. Inc. | Priest Brook | Leominster |
| 11. | Groton School | Nashua River | Groton |
| 12. | Hollingsworth & Vose Co. | Squannacook River | W. Groton |
| 13. | Injectronics Inc. | Coachlace Brook | Clinton |
| 14. | James River Fitchburg | Flag Brook | Fitchburg |
| 15. | James River Paper Co. | Nashua River | Pepperell |
| 16. | Kelly Co., Inc. | Counter Pane Brook | Clinton |
| 17. | Lab Circuits D.B.A. | intermittent stream to Nashua River | Groton |
| 18. | Dept. of Corrections | Whitman River | Gardner |
| 19. | Dept. of Corrections | Nashua River | Shirley |
| 20. | MWRA Clinton WWTP | South Branch Nashua River | Clinton |
| 21. | DPW Water Purif. Plant | Monoosnoc Brook | Leominster |
| 22. | Pepperell WWTP | Nashua River | Pepperell |
| 23. | Pepperell Power Assoc. | Nashua River | Pepperell |
| 24. | Polysar Inc. | Wass Brook | Leominster |
| 25. | River Terrace Healthcare | North Nashua River | Lancaster |
| 26. | St.Benedict/St.Theresa | unnamed stream to Nashua River | Stillriver |
| 27. | Shell Oil Co. | Muddy Brook | W. Boylston |
| 28. | Simonds Cutting Tools | Nashua River | Fitchburg |
| 29. | Tenneco Inc./Gas Pipeline | unnamed brook to Nashua River | Lancaster |
| 30. | Tucker Housewares | Fall Brook | Leominster |
| 31. | Van Brode Milling Co. | Nashua River | Clinton |
| 32. | Tennessee Gas Pipeline | North Nashua River | Leominster |




Location of aquifers studied and infiltration sites in the Nashua River basin.

FIGURE 6




Principal streams and areas of stratified drift in the Nashua River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 276.)

FIGURE 7

## BIOLOGICAL RESOURCES

The Nashua River basin, in particular the case study area, is a highly diversified ecological system supporting a variety of vegetation and wildlife. This was not always the case though as the Nashua River, twenty-five years ago, was listed as one of the top ten polluted rivers in the country. Heavy use of the river as a dumping area for municipal and industrial wastes since the 1800's had reduced the waterway to a slow moving, open sewer. The waterway could not be used for much of anything, often smelled badly, and was not desirable to live near. A grass roots movement to clean-up the river was begun in the early 1960's. After much effort on the part of the Nashua River Watershed Association, town administrators, state and Federal government officials, and with the backing of the Federal Water Pollution Act of 1972, the way in which the waterway was treated, changed. Water quality standards were instituted and enforced to improve wastewater discharges, treatment plants were built, and conservation lands were set aside to protect against overdevelopment. Today, as a result of this effort, the Nashua River is a popular spot for canoeing, fishing, hiking, and bird watching.

### Vegetation

A detailed description of wetland plant communities occurring in the study area is beyond the scope of the study. Common species in forested floodplain wetlands in central Massachusetts, however, generally include red maple, swamp white oak, slippery elm, silver maple, birches, speckled alder, sweet pepperbush, swamp azalea, highbush blueberry, arrowwood, skunk cabbage, jewelweed, cardinal flower, and cinnamon fern. Species typical of scrub-shrub wetlands include speckled alder, dogwoods, sweet pepperbush, meadowsweet, buttonbush (near open water), highbush blueberry, willows, skunk cabbage, and cinnamon fern. Common species in emergent wetlands include cattail, sedges, grasses, woolgrass, water smartweed, and pickerelweed.

About 25 percent of the study area is forested upland. Common hardwood species in the overstory include oaks, sugar maple, American beach, birch, and hickory. White pine is common in former pastureland and hemlocks occur on cool, north facing slopes (Fletcher, 1990).

Most of the remaining upland in the study area is cropland or oldfield. Extensive natural grasslands are also present at the Bolton Flats.

### Wildlife

The diverse wetland and upland community types present in the study area provide habitat for a great variety of mammals, birds, reptiles, and amphibians.

Mammals likely to be present in the area include river otter, beaver, muskrat, mink, fisher, weasel, red fox, eastern coyote, snowshoe hare, cottontail rabbit, white-tail deer, raccoon, striped skunk, woodchuck, porcupine, gray squirrel, flying squirrel, chipmunk , and several species

of mice, voles, shrew, and bats (Fletcher, 1990; Corps of Engineers, 1990). Among these, beaver, mink muskrat, raccoon, fisher, and fox are most frequently trapped (Hoight, 1992).

Numerous species of songbirds, waterfowl, raptors, and other birds occur in the study area, including about 140 resident or migratory species which may breed in the area (see DeGgraff and Rudis, 1987). Two hundred and twelve species have been reported from the Bolton Flats, including 87 species which are known to nest at the area (Fletcher, 1990). The Bolton Flats, Oxbow National Wildlife Refuge, and Pepperell Pond also provide excellent habitat for migrating Canada geese and other waterfowl.

Common reptiles and amphibians likely to occur in the study area include red-backed salamander, American toad, spring peeper, bullfrog, leopard frog, wood frog, snapping turtle, painted turtle, northern water snake, eastern garter snake, and northern black racer (DeGraff and Rudis, 1987).

Fish

The Nashua River supports a good warmwater recreational fishery (Fletcher, 1990). Based on 1974 Massachusetts DFW sampling of the main-stem Nashua River in Pepperell and Ayer, the most common fish present in the study area are white sucker, goldfish, sunfish, shiners, bullhead, largemouth bass, and pickerel.

The Squannacook and Nissitissit rivers, both major tributaries of the Nashua River, are heavily stocked with trout and considered to be two of best trout streams in Massachusetts (Fletcher, 1990).

Rare, Threatened, or Endangered Species

State listed threatened or endangered species known to occur in the study area include upland sandpiper, grasshopper sparrow, pied-billed grebe, northern harrier, and Blanding's turtle.

State listed "special concern" species known to occur in the study area include blackpoll warbler, American bittern, osprey, Cooper's Hawk, sharp-shinned hawk, spotted turtle, wood turtle, eastern box turtle, northern water shrew, southern bog lemming, Mystic Valley amphipod, blue spotted salamander, and climbing fern.

Two federally endangered species, the bald eagle and peregrine falcon, occur in the area as transients.

## WITHOUT PROJECT CONDITION

The first task in quantifying the costs and benefits of our case study is to determine the "without project condition". The future condition of the NVS areas will directly impact the analysis that is attempted. Specifically, the amount of storage area that will be lost through development in the future must be estimated. Once that is done then there are several alternative ways to quantify the costs and benefits of an NVS project.

For instance, one method would involve making a projection of the future amount of total storage area that will be lost. For illustration purposes, assume 30 percent. The cost of the NVS project would be the protection of all of the storage area in order to prevent their loss. The benefit would be the difference in expected benefits with a 30% storage loss versus no loss at all. This is what was done in the Charles River Study. This method could produce relatively high project costs, but would ensure that none of the storage area is developed and the project function is protected.

Another method would be to assume that in the future, all of the storage area is lost. The cost of a NVS project that would ensure only the assumed 30% loss takes place, would be the cost of protecting 70% of the storage area. The benefit would be the difference in expected benefits between a 100% loss and 30% loss. This method presents difficulties in that it may be based on an unrealistic future condition.

A third approach would be to assume that in the future, a specific amount of the storage area, assume 30 percent, will be lost. The cost of a NVS project would be the protection of only these 30%. The benefit would be the same as described in the first method. This method can also present problems because development could take place on other unprotected lands and the project function would be undermined. This method requires accurate prediction of what storage areas will be lost in the future.

For the purpose of this case study the third method described will be used. Based on reconnaissance level research, it appears about 70% of the storage area being examined is well protected against future development. Under the most extreme circumstances, a maximum of 30% of the storage area may be developed in the future. This is one of two without project scenarios that will be examined. During the study it was apparent that the lands under this 30% have varying amounts of protection through existing regulations. For example, the Wetlands Protection Act requires compensatory flood storage for projects within the 100 year floodplain. A more realistic without project condition may be the loss of 10% of the storage area. Therefore, a 10% loss scenario will also be considered in the case study. The benefit will be the difference in expected benefits with a 10% or 30% storage loss versus no loss at all. The cost of the project would be the protection, through outright purchase and/or establishment of CR's, of the 10% or 30% of storage area. This method of analysis was seen as acceptable for this case study due to the large number of identifiable protected lands in the study area. However, use of this method in either scenario assumes that it is possible to identify and acquire those lands which would otherwise be developed.

Finally, it is assumed in this analysis that a percentage of land developed is equivalent to the same percentage of storage area lost. In reality, there can be a difference between development and complete functional loss of storage area. Development can take place on a parcel of land and some storage capacity remain. However, that difference is very difficult to determine and therefore, in this analysis, these two terms are considered equal.

## COSTS OF PROTECTING NVS AREAS

There are generally two ways of protecting natural valley storage areas: instituting some form of restriction on a parcel of land or purchasing the land outright. Donated land is also a way of obtaining and protecting a parcel, but not a dependable one. As part of this case study, the first two mentioned avenues were explored.

Several land trusts in the study area were contacted to determine the prices they were paying to protect floodplain lands. With regard to conservation restrictions the information was very limited. Several factors including surveying, appraised value, title search, recording, and monitoring, make up the cost of putting a conservation restriction into place. The individual costs vary greatly according to the parcel's size and market value. All groups contacted stated that there was no average cost for CR's. Depending on the situation, the cost could be as low as a couple hundred dollars per acre or as high as a couple thousand dollars per acre. With regard to fee simple or purchasing the lands to protect them, the land trusts gave average, per acre costs of around $1,500 to $1,700.

Corps' real estate personnel conducted a limited analysis of land values in the study area. Based on their research it was determined that the land cost varied, but that an average cost of $2,000 per acre was suitable for our case study. A more detailed cost analysis would be needed to refine this estimate. In any event, the value seemed reasonable in light of the Massachusetts Department of Fisheries, Wildlife & Environmental Law Enforcement letter of September 18, 1990 which indicated their average purchase price, for wetland and upland combined during the years 1988-1990, averaged about $1,500 per acre.

For purposes of this case study an average price of $2,000 per acre for protecting the lands will be used. This value could be less if CR's were employed. However, due to the uncertainty of costs involved through that avenue of protection, the average purchase price will be the basis of the cost analysis. Purchasing 10% or 480 acres of NVS area would cost $960,000. Purchasing 30% or 1440 acres would cost $2,880,000. These are total investment costs. The annual cost, based on an interest rate of 8 1/4% and a period of analysis of 50 years, is $81,000 and $242,000, respectively. Annual operation and maintenance costs are not included in these figures.

## BENEFITS OF PROTECTING NVS AREAS

The benefits for the case study were calculated using a "without project condition" versus a "with project condition" analysis framework. In comparing the without and with project conditions, the improvements that would occur with a project can be clearly analyzed and the benefits of the improvement can be determined. As demonstrated previously, the without project condition must include a specific amount of storage area that is projected to be lost. In our case study, the projected amounts are 10% and 30% of the storage area. The benefits of a project are then determined by analyzing the effects of the loss of storage including:

increased flood damages, the loss of wildlife habitat, recreational opportunities, or other values. The following discussion will focus on quantifying various benefit categories using methodologies described earlier in this report. Where information was lacking or the effort beyond the scope of this study, the steps needed to quantify the benefit are included.

Flood Damage Reduction

For the case study, two flood prone areas in the City of Nashua, located on the Nashua River, were chosen for the application of the flood damage reduction benefit methodology (see Figure 5). These two areas were chosen because they are located downstream of the natural valley storage areas and could be affected by increased flood stages if the storage areas were lost. It is important to note that this analysis is not a comprehensive review of the flood reduction benefits of NVS. The purpose of this analysis is to solely demonstrate the evaluation technique.

Reach 1 is a damage area located in the city of Nashua on the Nashua River above Mine Falls Dam, near the border of Nashua and the town of Hollis, New Hampshire. The damage area contains 87 structures, all of which are residential structures, and many of which are contained in several trailer parks. Of the 87 structures, 75 are trailers and 12 are single family homes. Reach 1 includes houses and trailers located on Marina Drive, Riverside Circle, Cheryl Street, LeeAnn Street, Xenia Street, Fotene Street, Blank Street, Natick Street, Cheshire Street, Tilton Street, Winchester Street, Sunset Street, and Waterview Trail.

Reach 2 is a damage area located in Nashua on the Nashua River below Mine Falls Dam and above Jackson Mills Dam. Reach 2 is located downstream of Reach 1, and is located just upstream of downtown Nashua. Like Reach 1, Reach 2 contains only residential structures. The damage area includes 18 single family homes, 2 duplexes, and 122 townhouse-style apartment units, for a total of 142 residential units, and includes structures located on Miami Street, Burns Street, Tampa Street, Bitirnas Street, and Newton Drive.

The first step in calculating flood damage reduction benefits is to conduct a flood damage survey. The three critical pieces of information needed are the type of structure, first floor elevation, and the elevation of the start of damages. The first floor elevations were obtained using records provided by the City of Nashua. The type and low water entry point of each structure were determined through a field survey conducted by Corps' personnel. Structures located within the flood zone (100-year and 500-year) were considered during the survey.

Since all of the structures in the two damage areas are residential, typical stage damage functions were used to estimate the damages that would occur in each structure at various levels of flooding. The typical damage functions used were developed by the New England Division, Corps of Engineers, and are based on an engineering analysis of the repair and replacement costs for typical structures and contents. The typical residential structure curves used include a small one-family house, medium

one-family, large one-family, trailer home, and apartment unit. The combination of the collected field data with the typical damage functions yield a total stage-damage curve for each of the two reaches.

The second step in calculating flood damage reduction benefits is to combine the total stage-damage curve for each reach with the hydrologically developed stage-frequency curve for each reach. The result of this second step is the determination of the recurring and expected annual losses for each reach. The stage-frequency curves graphically depict the change in flood elevation, for varying frequency of flood events, between the existing conditions (no loss of NVS areas) and the expected future condition (10% and 30% NVS loss).

The calculation of these curves involved a detailed hydrologic analysis. The availability of several gages along the Nashua River enabled the calibration of a computer model of the river. The March 1936, September 1938, and May/June 1984 storm events were used to provide historic flood data needed for the model calibration. The 1936 flood event was used as the flood of record and represented an upper limit of the NVS extent and the basis for estimating storage loss. Percent losses were applied to the cross sections of the 1936 flooded area. The effect on the downstream flood hydrograph was then measured with each projected loss scenario. Discharge-frequency and stage-discharge relationships were determined for the two damage areas. Stage-frequency curves for the two areas were then determined from these. For a 1% chance of exceedance (100-year) event, a flood stage increase of 0.6 feet and 1.2 feet was calculated for the area above Mine Falls Dam, for the 10% loss and the 30% loss scenarios, respectively. For a detailed description of the analysis refer to Appendix C.

Recurring losses are those potential flood losses that are expected to occur at various stages of flooding under current development conditions. As the final output of the flood damage survey process, the dollar value of losses in the project area are determined for an array of events ranging from very likely to very rare events. Table 10, below, shows the losses expected for selected events for each damage reach under existing development conditions.

Table 10
Recurring Losses - Existing Conditions

| Flood Event | % Chance of Occurrence | Reach 1 | Reach 2 |
|---|---|---|---|
| 5-year | 20% | $ 15,200 | $ 0 |
| 10-year | 10% | $ 41,400 | $ 0 |
| 20-year | 5% | $ 158,900 | $ 0 |
| 25-year | 4% | $ 209,800 | $ 54,700 |
| 50-year | 2% | $ 496,600 | $1,507,600 |
| 100-year | 1% | $1,045,400 | $4,580,100 |

Expected annual losses are calculated by multiplying the recurring losses expected at each flood elevation by the annual percent chance of occurrence that each flood elevation will be reached, and then adding the

resulting figures together. The resulting total equals the expected annual losses for that damage reach, and represents the average annual flood losses that can be expected to occur given the entire range of probabilities associated with floods of different magnitudes. The effectiveness of a flood damage reduction plan is measured by the extent to which it reduces expected annual losses. The expected annual losses for each of the two damage reaches examined in this analysis were calculated for existing development conditions, as well as for 10% and 30% storage losses. The resulting annual loss figures are shown in Table 11, below.

Table 11
Expected Annual Losses

| | Existing Conditions | 10% Loss | 30% Loss |
|---|---|---|---|
| Reach 1 | $ 47,200 | $ 51,700 | $ 62,200 |
| Reach 2 | $107,900 | $122,600 | $148,500 |
| Total | $155,100 | $174,300 | $210,700 |

The flood damage reduction benefits are determined by calculating the difference between the annual losses assuming storage area is lost, and the annual losses under existing conditions. Table 12, below, shows the annual flood damage reduction benefits for each reach assuming a 10% loss of storage and a 30% loss of storage.

Table 12
Annual Flood Damage Reduction Benefits

| | 10% Loss Scenario | 30% Loss Scenario |
|---|---|---|
| Annual Flood Damage Benefits | $19,200 | $55,600 |

Cost of Flood Insurance Premiums

Benefits for flood insurance cost savings were calculated using two different methods. The first method is allowed under Corps guidelines. Under current Corps regulations, only the reduction in the administrative overhead costs of the flood insurance program, measured on a per policy basis, can be counted as project benefits. For the case study, which is not limited to benefit categories allowed in Corps analyses, the actual cost of the policy paid by property owners is used as the benefit. The current FIA (Flood Insurance Administration) overhead cost is $111 per policy. The current average policy cost used was $350 per policy. The use of either of these figures results in benefits expressed in annual terms, because both the overhead costs and the actual policy costs are incurred annually.

In order to determine the benefits under either method, it must be determined how many structures would be in the 100-year floodplain without a project but would not be in the 100-year floodplain with the project. In the without project condition, the elevation of the 100-year flood will increase as the storage area is lost. With the project, the storage area

is preserved, and flood stages do not increase. Benefits for flood insurance costs saved were calculated by determining the number of structures which currently have first floor elevations above the 100-year flood elevation, but which, in the without project condition, would have first floor elevations equal to or below the 100-year flood elevation.

In this case study, an analysis of the first floor elevations and the 100-year flood elevations in each scenario yielded the following results. In the 10% loss scenario, one additional structure's first floor would be located at or below the 100-year event elevation. In the 30% loss scenario, a total of two additional structures' first floors would be located at or below the 100-year flood elevation. A more complete analysis would involve redelineating the flooplain boundaries to determine all the structures affected. This was beyond the scope of this study. Based on the method used, the flood insurance cost savings benefits are as follows. Using the Corps guidance approach of taking the administrative cost of $111 per policy per year as the benefit, the annual benefit under the 10% loss scenario equals $111, and the annual benefit under the 30% loss scenario equals $222. Using the approach of taking the yearly policy cost of approximately $350 per year as the benefit, the annual benefit under the 10% loss scenario is $350, and the annual benefit under the 30% loss scenario is $700. The flood insurance benefits are summarized in Table 13.

Table 13
Flood Insurance Cost Savings

| | 10% Loss Scenario | 30% Loss Scenario |
|---|---|---|
| Corps Approach (administrative cost savings) | $111 | $222 |
| Policy Cost Approach | $350 | $700 |

### Enhanced Property Values

There may or may not be enhanced property value benefits to a natural valley storage project on the Nashua River. Whether there would be such benefits would depend on the different determinants of property values along the Nashua River and the degree to which each determinant affects the property values. There are many factors such as the regional economic condition, the demand for housing, the age and condition of a structure, and other aesthetic values which can affect property values. It is difficult to determine the effect, if any, that being near preserved open space or conservation land will have on property values. Even if it were determined that there was a positive effect, it would be even more difficult to determine the magnitude of the effect. Due to the difficulties involved, these benefits were not calculated in this case study.

### Recreation

Currently, the Nashua River and the lands along the river are used for a variety of recreational activities, including canoeing, boating,

fishing, hiking, nature walks, and other related activities.

Usage figures were not available for any of the recreation areas in the study area. The only usage data that was available was a usage figure of 170,000 people per year at the Great Meadows Wildlife Refuge area, which is located on the Sudbury River in Sudbury, Massachusetts. The two areas are in proximity to one another and serve the same general population area. So, in the absence of any other data, the 170,000 people per year usage figure was used for demonstration purposes as an estimate of recreation use.

Three methods of estimating the recreational value of the NVS areas were considered in this case study. The first one is the unit day value (UDV) method.

To use the unit day value (UDV) method to estimate recreational benefits, the first step is to estimate the dollar value of the recreation opportunities available in the study area by assigning the UDV points according to the UDV guidelines. The guidelines and parameters for assigning the point values are shown in Appendix D. Due to the lack of specific usage figures for each different recreation activity in the study area this UDV analysis was done viewing the entire study area as one site. All of the recreational opportunities available in the study area were combined and evaluated together. Once the point values were assigned, the total point value was converted to a dollar value based on the conversion table also shown in Appendix D. This information is part of current Corps of Engineers' guidance.

Table 14
Assignment of Unit Day Value Points

| | Point Assignment |
|---|---|
| Recreation Experience | 20 |
| Availability of Opportunity | 6 |
| Carrying Capacity | 8 |
| Accessibility | 14 |
| Environmental | 14 |
| Total | 62 |
| $ UDV Conversion | $5.40 |

The above point assignments were made based on the guidelines shown in the appendix and using the following rationale. For the characteristic "Recreation Experience", a value of 20 out of 30 possible points was assigned. The reason being that the recreational areas in the study area contain a variety of activities including, hiking, educational nature walks, fishing, and canoeing, and that several of these activities could be considered high quality activities. For the characteristic "Availability of Opportunity", a value of 6 out of 18 was assigned. The reason being that similar recreational opportunities can be found within

one hour travel time, but similar quality opportunities could not be easily found within 30 minutes travel time. For the characteristic "Carrying Capacity", a value of 8 out of 14 was assigned. The reason being that the site was judged to have good, adequate facilities needed to conduct the recreation activities available. For the characteristic "Accessibility", a value of 14 out of 18 was assigned. The reason being that the recreation sites in the study area are generally accessible by well-maintained public roads. For the characteristic "Environmental", a value of 14 out of 20 was assigned. The reason being that the recreation sites were judged, in general, to have a high esthetic quality. The sum of all of these point assignments yields a point total of 62. Using the conversion table provided in table D-2 in the appendix, the recreation sites in the study area have a value approximated at $5.40 per user per day.

It is difficult to estimate the way in which the recreation opportunities currently available in the study area would be affected in the without project condition if some of the storage areas are lost to development. For estimation purposes, it is assumed in this case study that in the 10% loss scenario, the total recreation use in the study area would be reduced by 10%, and that in the 30% loss scenario, the total recreation use would be reduced by 30%. Thus, it is estimated that in the 10% loss scenario the recreational usage will decline by 17,000 users per year (170,000 X 10% = 17,000), and that in the 30% loss scenario the usage will decline by 51,000 users per year (170,000 X 30% = 51,000). The value of these losses is estimated by multiplying the usage loss by the unit day value of $5.40. Under the 10% loss scenario, the loss is valued at $91,800 (17,000 users X $5.40/user = $91,800). Under the 30% loss scenario, the loss is valued at $275,400 (51,000 users X $5.40/user = $275,400). With the NVS project, these losses would be prevented. The recreation benefits equal the value of the losses. The recreation benefits are summarized below in Table 15.

Table 15
Recreation Benefits - Unit Day Value Method

| | 10% Loss Scenario | 30% Loss Scenario |
|---|---|---|
| Annual Recreation Benefits | $91,800 | $275,400 |

Use of the travel cost method to estimate recreational benefits was considered, but determined to require extensive data collection which was beyond the scope of this case study. If the travel cost method were to be used, it would be necessary to survey a sample of the users of the recreation sites in the study area. The most effective survey would likely be done through on-site interviews. In the survey, the most important information that would need to be collected would be the distance the user travelled to get to the site, the time it took the user to get there, the primary purpose of the trip, and the number of visits the user expects to make that year to the site. Some general demographic information should also be collected. The travel cost data collected could then be statistically analyzed to estimate the demand curve for each recreation site. The value of the recreation activities could then be estimated by calculating the area under the demand curve.

The contingent value method (CVM) was also considered for estimating the recreation benefits from a NVS project. The CVM was also determined to be beyond the scope of this case study. If the CVM were to be used, a survey would have to be developed asking specific questions regarding the recreational opportunities available on and along the Nashua River. The survey would give the respondent the opportunity to value the recreation opportunities. The results of the survey could then be statistically analyzed to estimate the dollar value of the recreation opportunities.

Recreation Induced Regional Economic Development

The calculation of recreation induced regional economic development benefits was also determined to be beyond the scope of this case study. However, if they were to be calculated, the following steps would be required. The first step would be to determine the number of people per year which take advantage of the various recreation opportunities on and along the Nashua River. The second step would be to estimate the average amount spent in the region by each user. This would most effectively be done by analyzing the usage patterns of the different types of users, and then surveying a sample of each type of user. Once these first two steps are completed, the data can be combined to determine the total dollar value of the expenditures brought into the regional economy by the recreational site. In general, recreational sites which are used by people who travel long distances, eat in local restaurants, purchase supplies in area shops, and stay overnight, have the greatest economic impact on the regional economy. Recreational sites which are used primarily by people living very close to the site and for short periods of time, eliminate much of the need for restaurants and stores, and may have much less or even no impact on the regional economy.

In researching this case study, information was obtained from the US Fish and Wildlife Service (USFWS) concerning recreation expenditures for several different types of recreation activities. Every five years, USFWS conducts a detailed survey of recreation usage and publishes the results. The most recent survey for which results are available was done in 1985. The results are shown in the report entitled, "1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation". A more recent survey was conducted in 1990, the results of which are expected to be available by January 1993. The data available in the survey was examined for use in this case study. However, it was found to be not applicable. The data available showed total expenditures, by state, and for the nation for three classes of recreational activities: fishing, hunting, and "wildlife associated recreation". While such data would be useful for determining the overall economic impact of recreation on the entire state's economy, there is no way to determine what portion of the total state expenditures are spent as a result of the specific recreational sites being available in the study area. Only those expenditures made at the site or made as a result of those sites being available, should be included in an analysis of the economic impact of those sites. Since such site specific data was not available from the USFWS survey, it was not used for further benefit analysis in this case study.

The third step in calculating recreation induced benefits would then be to determine the extent of the multiplier effect, which is the degree to which $1 spent in the region increases the total income and employment of the region. The multiplier effect can be determined through the use of input-output models. There are a variety of input-output models available through various sources. There is an input-output model, RIMS II, which is available through the US Department of Commerce and which is frequently used in government analyses. Another input-output model which could be used is called EIFS, the Economic Impact Forecasting System, which was developed by the Department of Defense and is available through the University of Illinois at Urbana-Champaign, Department of Urban and Regional Planning. Use of either model would yield an estimate of the total economic impact of the recreation expenditures in the regional economy. If time and funds are not available for the use of a model, an economic multiplier developed in similar studies could be used as an approximation. Research would have to be done to locate studies done by governmental agencies, planning agencies, or other researchers, in which multiplier effects for recreation activities were calculated. The multiplier value could then be multiplied by the regional recreation expenditures calculated in step 2, above. The resulting figure would be an approximation of the total economic impact of the recreation activities on the regional economy. In general, multiplier values for recreation, tourism, and related activities tend to range in value from 1.5 to 2.5.

Water Quality

Water quality benefits for this case study were not quantified. No identifiable relationship was able to be made between the storage areas and water quality. The Nashua River is currently rated as having Class B waters. Though the location of each point discharge is known, the effect NVS areas have on improving the water quality of the Nashua River was not established. The existence of this relationship and/or to what extent it might exist would require detailed field sampling and monitoring. If applicable data were available for this case study, two methods in particular were seen as useful for calculating water quality benefits.

The first such method is the replacement cost methodology. Figure 8 is a flow chart that describes the procedure for using this method. NVS areas may treat wastewater/runoff or provide a clean surface water supply at or downstream of the area. The effect on these services, due to the loss of a certain NVS area, must then be determined. The benefit of protecting the NVS area is the cost saved in providing an improved or alternate form of service.

The second method presented is the hedonic price technique. A flow chart describing the method is shown in Figure 9. This method approaches water quality from an aesthetic point of view. Water quality benefits are measured as a function of the cost an owner adjacent to the water is willing to pay to protect a NVS area that contributes to the river's aesthetic qualities. This method requires a detailed analysis of real estate, with and without a view of the water, and carefully prepared interviews with the property owners.

### Erosion Control

The erosion control benefit calculation can be done in one of two ways. The first method identified is again the replacement cost methodology. In this case the erosion impact on an individual property or properties is measured, that results from excavating or filling a NVS area. The benefit measured is the avoided cost of providing extra protection against the increased erosional effects. Figure 10 describes the process in more detail. The method is certainly very applicable to coastal situations but can also be used in riverine cases. Again, due to the lack of information available at this level of study, a determination of the increased erosion with storage loss was not calculated.

The other method found to be useful for this benefit category is the damage cost methodology. Similar to the replacement cost method, the effects of increased erosion are measured. The avoided cost of repairing damaged property is the benefit to be gained by preserving NVS areas. Figure 11 describes the process in detail. Again, the lack of measurable data relating storage loss to erosion in the case study prevents a benefit from being calculated.

### Groundwater

Potential benefits to groundwater can also be calculated using the replacement cost methodology. Groundwater sources to be used in the future or that are currently being used, are first identified. A relationship between the NVS areas and the aquifer, and the impact the loss of storage would have on the water supply must then be identified. The benefit of protecting the storage area is the avoided cost of providing an alternate or enhanced source of groundwater. Figure 12 is a flow chart that describes the process in more detail.

An exact relationship between the major municipal groundwater supplies and natural valley storage areas identified in the case study area could not be determined. Available information appears to indicate that aquifers in the area primarily discharge to wetlands, but during certain times of heavy draw-down may also experience recharge. Of the relationship between upland storage areas and aquifers, there was no information. Without specific information on the relationship between the two, a determination of the benefit gained by protecting the storage area could not be made.

### Commercial Products

Based on available data, approximately ten individuals harvest furbearers in the project area on a regular basis. These individuals concentrate on muskrat and mink, but some beaver, otter, and fox are also trapped.

No information about the number of furbearers harvested annually from the study area or their sale value is available. The average annual income from sale of raw pelts in Massachusetts ranges from about $400 to

$1500 dollars per trapper (see data provided by Decker, 1992). Using these values, and assuming that ten trappers are active in the study area, the annual value of furs trapped from the 4800 acre area ranges from about $0.80 to $3.10 per acre. Because virtually all furbearers trapped in the area are probably wetland dependent species, it may be more appropriate to calculate per acre furbearer yield based solely on wetland acreage. Assuming that 42 percent of the study area is wetland, furbearer value ranges from $ 2.00 to $7.40 per wetland acre per year. An average value would be $4.70 per wetland acre. In the 30% scenario, 96 acres of wetland could be lost. The benefit of protecting the 96 acres would be $450/year. In the 10% scenario, assume 1/3 of the area or 32 acres are lost. The benefit of protecting the 32 acres would be $150/year.

No known commercial hunting, fishing, or logging takes place in the study area, so a benefit determination for these commercial products was not attempted.

Agriculture

The value of wetlands and floodplains for agriculture can be determined by calculating the net value of the production of the lands. Net value is determined by subtracting the production costs from the gross market value of the goods produced. The agricultural production value for the agricultural areas of land in the case study area were estimated. The results are shown in the two paragraphs below. However, in examining the potential benefits of a natural valley storage project, it was determined that the agricultural production value must also account for alternative land use. The reason becomes clear when analyzed within the without project/with project condition framework. In the with project condition, the storage areas in the study area will be preserved, and the storage area lands that are currently being used for agricultural production probably would continue to be used for that purpose. In the without project condition, the agricultural lands in the study area may be developed. Where before the lands produced agricultural products, after being developed, the lands may produce other products, such as space for housing, stores, or a factory. If development does occur, it will occur because it is demanded in the marketplace in the same way that the agricultural products are demanded in the marketplace. In comparing the with and without project conditions then, there could be a change in the nature of the goods produced by the land. The value of the lost agricultural products cannot be counted unless the value of the alternative use is counted as negative benefits or project costs. This was not able to be calculated in this study. Agricultural production value was determined to be a valid and useful way of determining the gross value of a resource, but did not readily yield figures that could be translated into project benefits.

Although this method was not able to be used to calculate a project benefit, data on agricultural production in the study area was collected to show how agricultural production value can be used to calculate resource value. Based on the open space maps, it was determined that cropland makes up approximately 17% or 816 acres of the total natural valley storage in the study area. It was determined that 288 acres of the

## REPLACEMENT COST METHODOLOGY

## WATER QUALITY BENEFITS

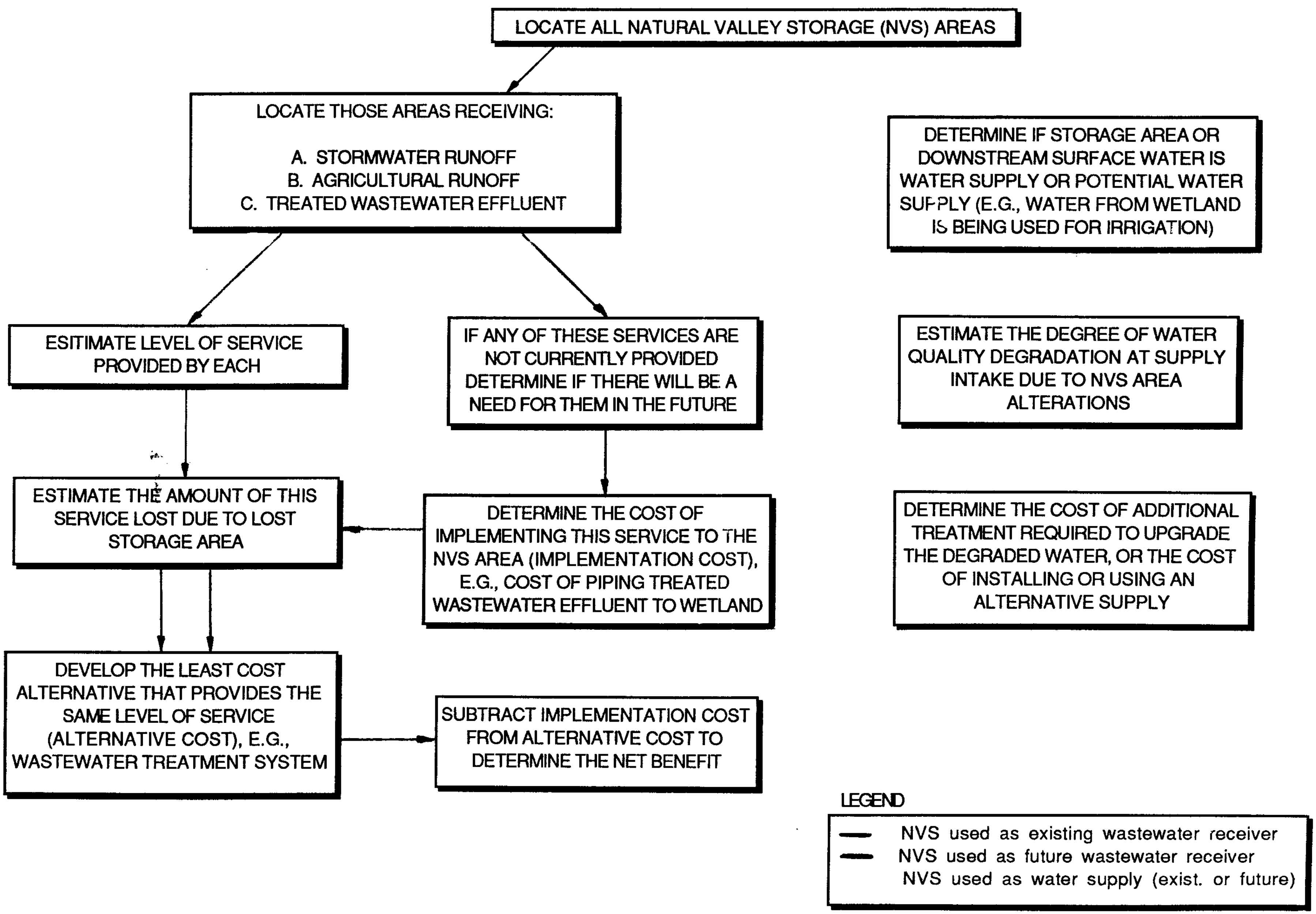



FIGURE 8

## HEDONIC PRICE TECHNIQUE

## WATER QUALITY BENEFITS

LOCATE ALL NATURAL VALLEY STORAGE (NVS) AREAS

↓

LOCATE PROERTY ADJACENT TO NVS AREAS WITH PICTURESQUE VIEWS OF SURFACE WATER (NASHUA RIVER, TRIBUTARIES, WETLANDS, LAKES, ETC.)

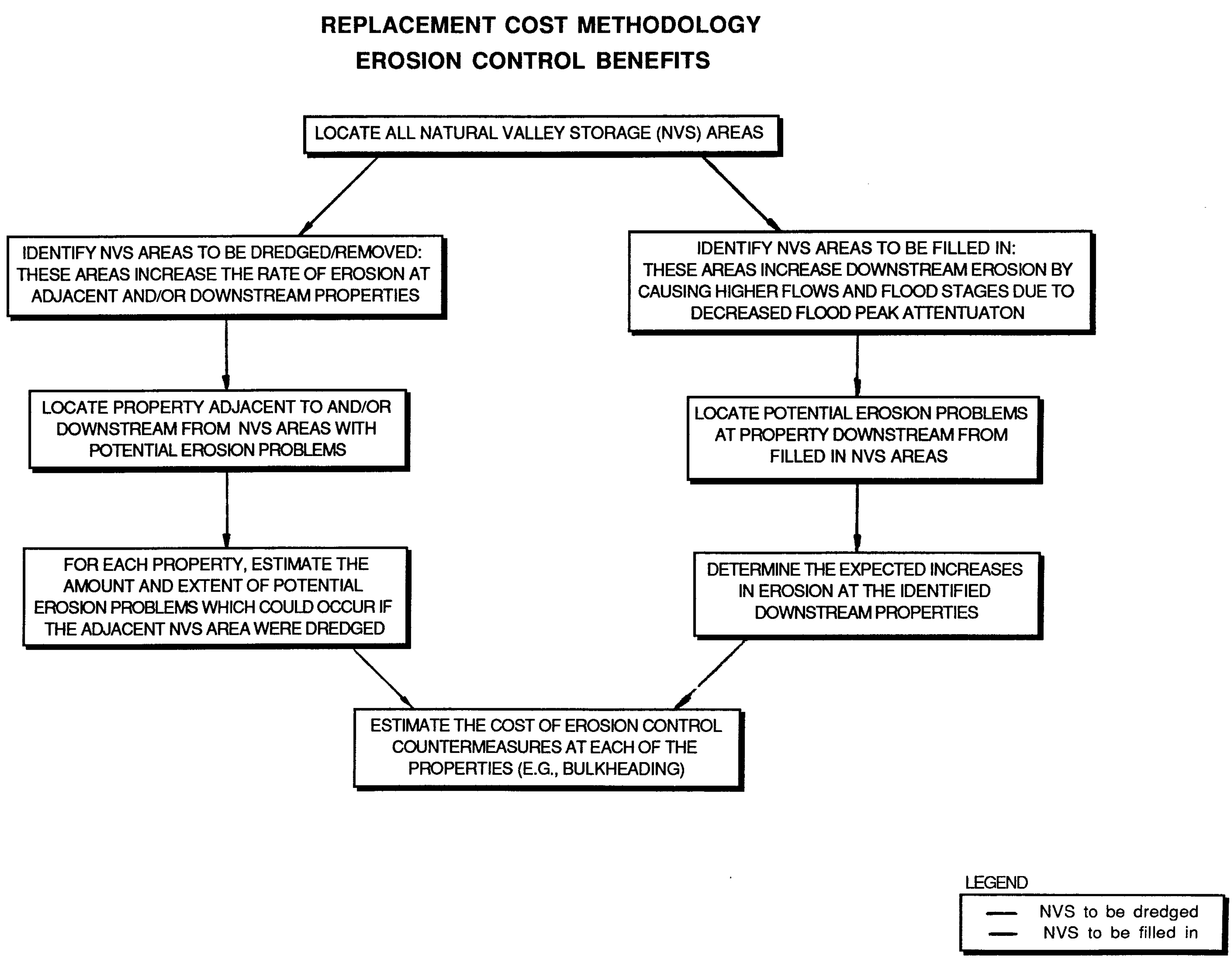
↓

DETERMINE HOW MUCH PEOPLE WILL BE WILLING TO PAY FOR EACH WETLAND OR NVS AREA KNOWING THAT IT WILL BE FILLED IN, DESTROYED

-COMPARE SALES OF SIMILAR PROPERTIES WITHOUT VIEWS

-INTERVIEW PROPERTY OWNERS

FIGURE 9



REPLACEMENT COST METHODOLOGY
EROSION CONTROL BENEFITS
LOCATE ALL NATURAL VALLEY STORAGE (NVS) AREAS
IDENTIFY NVS AREAS TO BE DREDGED/REMOVED: THESE AREAS INCREASE THE RATE OF EROSION AT ADJACENT AND/OR DOWNSTREAM PROPERTIES
IDENTIFY NVS AREAS TO BE FILLED IN: THESE AREAS INCREASE DOWNSTREAM EROSION BY CAUSING HIGHER FLOWS AND FLOOD STAGES DUE TO DECREASED FLOOD PEAK ATTENTUATON
LOCATE PROPERTY ADJACENT TO AND/OR DOWNSTREAM FROM NVS AREAS WITH POTENTIAL EROSION PROBLEMS
LOCATE POTENTIAL EROSION PROBLEMS AT PROPERTY DOWNSTREAM FROM FILLED IN NVS AREAS
FOR EACH PROPERTY, ESTIMATE THE AMOUNT AND EXTENT OF POTENTIAL EROSION PROBLEMS WHICH COULD OCCUR IF THE ADJACENT NVS AREA WERE DREDGED
DETERMINE THE EXPECTED INCREASES IN EROSION AT THE IDENTIFIED DOWNSTREAM PROPERTIES
ESTIMATE THE COST OF EROSION CONTROL COUNTERMEASURES AT EACH OF THE PROPERTIES (E.G., BULKHEADING)
LEGEND
NVS to be dredged
NVS to be filled in


FIGURE 10

## DAMAGE COST METHODOLOGY

## EROSION CONTROL BENEFITS

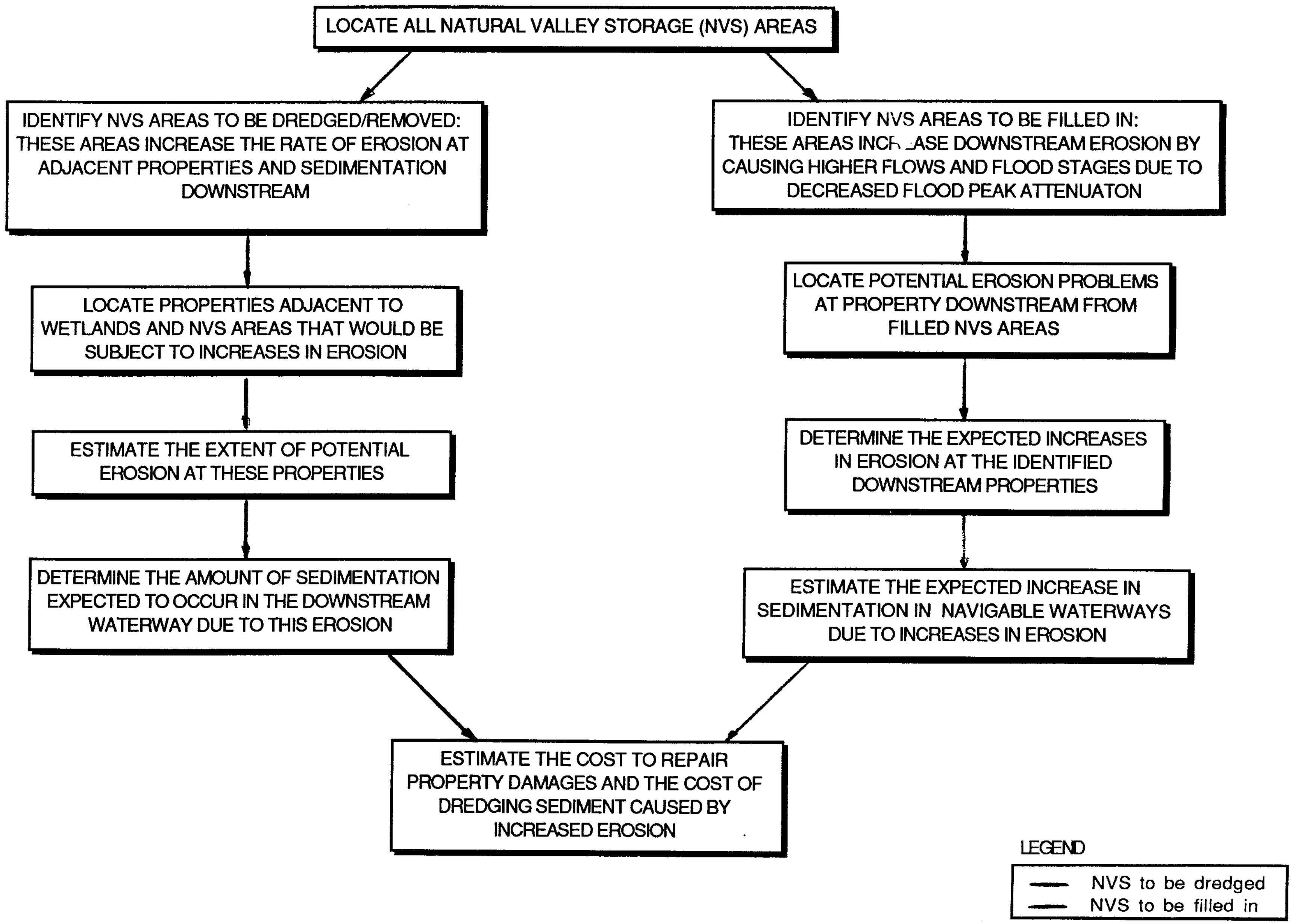



FIGURE 11

# REPLACEMENT COST METHODOLOGY

## GROUNDWATER BENEFITS

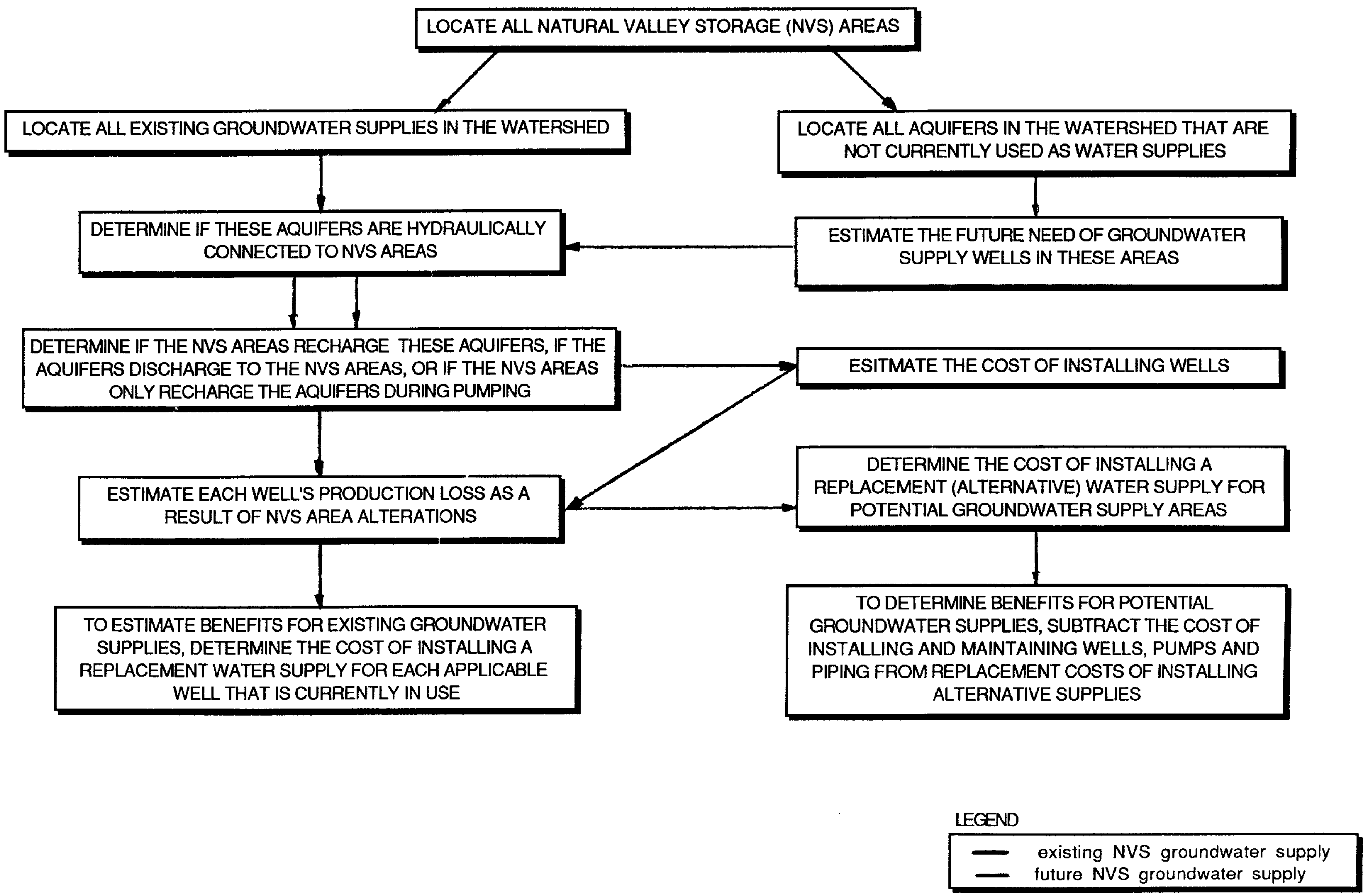



FIGURE 12

816 acres of cropland are strictly protected and that the remaining 528 acres could possibly be lost to development. Again, using the open space maps, the approximate acreage of cropland in NVS areas for each community in the study area was determined. The Soil Conservation Service then provided information on the agricultural products produced in each community. The primary agricultural products in Pepperell are hay and silage corn; in Groton, vegetables and sweet corn; in Harvard, hay; and in Lancaster and Bolton, silage corn. In a more detailed study, the producers would be specifically identified and contacted to find out the specific items produced.

The Soil Conservation Service also provided information on the average yield of different agricultural products per acre, and the average market price per acre. This information, combined with the acreage and usage estimates, made it possible to estimate the annual gross value of the agricultural production on NVS areas in each town. For example, it was estimated that, of the NVS areas in Lancaster, there are 220 acres on which silage corn is grown. Silage corn was found to yield about 20 tons per acre and have a market value of $27 per ton. The gross value of the agricultural production in the NVS areas in Lancaster is $118,800 (220 acres X 20 tons/acre X $27/ton = $118,000). The next step required in the calculation is to subtract the production costs from the gross value to determine the net value. The average production costs per acre for the different agricultural products were obtained from a Cornell University study titled, "Feasibility of Producing and Marketing Fresh Vegetables in Central and Western New York", A.E. Research 91.1, February 1991, by Raymond Barnes and Gerald White, Department of Agricultural Economics, Cornell University. In general, production costs for the different agricultural products tended to range from 40% of the market value to 75% of the market value. Silage corn was found to have a production cost of about $300 per acre per year. The production costs for the silage corn produced on 220 acres in Lancaster thus equal $66,000 (220 acres X $300/acre = $66,000). The net value of silage corn on 220 acres in Lancaster thus equals $52,000 ($118,800 - $66,000 = $52,000). This equates to a net value of $236 per acre per year.

These same steps can be followed for the other types of agricultural production in the other communities. In following these steps for each of the cropland areas included in the NVS areas in Pepperell, Groton, Shirley, Harvard, Lancaster, and Bolton, the average net value of agricultural production was found to be about $580 per acre per year. The gross agricultural value of the NVS areas lost to development would be $306,200 ($580/acre X 528 acres = $306,000). The 10% loss scenario would produce a value one third this or $102,100. As explained previously, these values are not the benefits attributed to avoiding the storage loss. The alternate use value of these lands would need to be subtracted from these figures to derive the exact benefit.

Long-Term Carbon Storage

A method used for attempting to determine the economic value of carbon storage in wetlands and uplands in the case study was the replacement cost analysis. In this method, the cost of planting trees, that sequester the

same amount of carbon, is an estimate of the economic value of that carbon storage. Examples of values are shown in table D-3 in Appendix D.

Carbon storage values range from $60 per acre/year for emergent wetlands to $260/acre/year for forested wetlands. The weighted average for wetlands within the study area is about $220/acre/year. Forested uplands have a value of $660/acre/year.

An actual benefit calculation was not made using these average carbon storage values for reasons similar to those presented in the agriculture category. First, demand for the replacement of trees and shrubs to store the carbon could not be determined. Unless there is a need for its replacement demonstrated, then the benefit to society is questionable. Second, if there was a need for this replacement, to what extent would replacement need to take place. Development of NVS areas does not necessarily mean that all trees and shrubs are removed from the area; some amount of cover is usually left untouched. Also, a developed area may exchange a certain amount of trees or shrubs for another kind which would reduce the amount of impact expected to occur. If these issues could be addressed then a benefit calculation could be determined by simply multiplying the cost/acre/year and the amount of each type of vegetation to be lost without the project.

**TOTAL RESOURCE VALUE**

As described earlier, one way of evaluating the worth of NVS areas is to look at it as a whole. The cost of replacing an entire storage area, the amount of energy captured by an area, or the price people are willing to pay to protect a storage area, are all ways of measuring the total resource value. For purposes of this case study, three different methods were evaluated.

The replacement cost method was used to measure a wetland's worth by the cost of replacing, in kind, an acre of that wetland. An estimate of replacing upland was not calculated due to a lack of information. Wetland replacement cost can be estimated from either the actual cost of completed wetland construction projects or by estimating the cost of constructing a hypothetical wetland.

Although numerous wetlands have been built in Massachusetts under the state's Wetland Protection Act, no published information about the construction costs of these wetlands or other wetlands in the northeastern United States was available. Wetland restoration experts contacted indicate that construction costs vary widely, depending on real estate costs, type of wetland constructed, and local construction costs.

Wetland replacement cost was determined by estimating the hypothetical cost of constructing a 10 acre forested or scrub-shrub and emergent wetlands. Total planning and construction costs amount to about $84,000/acre for the forested wetland and $88,000/acre for the emergent wetland. A detailed breakdown of these costs is shown in Appendix D. Costs/acre could be substantially more or less depending on the amount of

excavation needed to reach proper grade, real estate acquisition costs, and local construction costs.

The benefit derived here would be the mitigation costs avoided (if such mitigation was required) by preserving the storage areas. For every acre of wetland protected in our case study, about $86,000 would be saved as result of mitigation avoided. Based on an interest rate of 8 1/4% and a period of analysis of 50 years this is equivalent to an annual cost of $7,200.

Another measure of total resource value is the energy analysis method. An estimate of the economic value of wetlands and forested uplands in the study area using the energy analysis method (Costanza et al., 1989) is presented in detail in Appendix D. This method uses the total amount of energy captured by an ecosystem as an estimate of its potential to do useful work. The approach involves valuing the gross primary production (GPP) of an ecosystem or community based on the cost of equivalent energy provided by fossil fuels. This method should theoretically place an upper limit on the economic value of products produced by the system. The analysis used followed the Costanza method, with the exception that values were calculated based on net primary productivity (NPP), rather than GPP. NPP was used because it seems to be a better measure of the potential of a system to yield useful outputs than gross primary productivity (GPP).

Wetland values determined by this technique ranged from $19/acre/year for riverine/open water habitat to $120/acre/year for emergent communities. The weighted average for wetland areas within the study area is about $47/acre/year. Forested uplands have a value of $90/acre/year.

Again, the values for both the replacement cost and the energy analysis methods was left in per acre format. The effect that development would have on each of these per acre values was not easily discerned and so the actual benefits to be gained by preserving the NVS areas is not known.

Finally, the contingent value method can be used to measure the total resource value of natural storage areas. Though only mentioned here in the case study, the contingent value method can be used to measure other benefit categories such as recreation, water quality, and aesthetics. Conducting an actual contingent value study to determine NVS area values was beyond the scope of this study. However, a simple hypothetical contingent value survey was developed to illustrate how the technique might be applied to the case study. The survey is shown in detail in Appendix E. Design of the study is loosely based on a contingent value study of willingness to pay for wetlands preservation in Kentucky (Whitehead, 1990).

The primary objective of the contingent value survey would be to determine the value of Nashua River natural valley storage areas that are at risk to future development. Value would be based on respondent willingness to contribute to a hypothetical "Natural Valley Storage Preservation Fund".

Massachusetts households would be the sampling unit. Households from each county in the state would be selected randomly from telephone directories. The number of households sampled from each county would be proportional to the county population.

The sample size required depends on the desired degree of statistical confidence, the likely variability in the data, and likely percentage of non-respondents. Sample size can be determined based on various statistical formulas or previous experience. Results obtained by Whitehead (1990) suggest that a sample size of about 700 would provide an adequate estimate of willingness to pay for natural valley storage preservation.

The survey would be administered by mail. Non-respondents would be contacted with follow-up letters. Respondents would be provided with a cover letter explaining the study and background information shown in the example survey. After reading the survey, respondents would be asked how much their household would be willing to contribute to the hypothetical fund in order to preserve the study area from development. Two sets of questionnaires would be administered. One would indicate that 30% of study storage areas will be lost over a period of time, say the next 50 years. The second set would state that a 10% loss would occur. All respondents would be asked a series of personal questions aimed at determining factors influencing willingness to contribute to the fund and to detect potential biases in the study.

Natural valley storage preservation value/acre would be determined by multiplying the average household contribution by the number of households in the state and dividing by the number of acres of NVS preserved. Regression analysis would then be used to examine relationships between willingness to contribute to the fund and various factors. Potential bias would be detected by comparing factors such as mean age and mean household income with state census data.

## BENEFIT/COST COMPARISON

As indicated earlier, the case study was conducted to demonstrate methods of quantifying the benefits and costs of preserving natural valley storage areas. This demonstration did not include the entire watershed, nor, due to time and funding, was every method pursued to completion. As a result, a benefit/cost ratio, the indicator of a project's economic feasibility, was not calculated as it would be misleading. If a benefit/cost ratio was calculated it would entail a comparison of annualized benefits vs annualized costs. For example, in this case study annual flood damage reduction benefits of $19,200 and $55,600 were determined for the 10% loss and 30% loss scenarios, respectively.

Corps of Engineers regulations require that benefits which will occur in the future be discounted to present value equivalents, based on the federal interest rate for water resources projects, in order to reflect the time value of money. The time value of money is the concept that $1 today is worth more that $1 in the future. In this case study, the without project condition projects that development will occur on certain

NVS lands in the future. The benefits to an NVS project are derived from the effects of that development. Since all of the projected development will not occur immediately, the benefits are in essence future benefits, benefits that will occur at some time in the future when the development occurs.

In order to calculate the annual benefits with the time value of money concept taken into account, it is necessary to estimate when in the future the projected development will occur. Since it is very difficult to make such a projection, several different calculations were made to show the range of possible values of the benefits depending on the assumption made. All of the following calculations were made using a period of analysis of 50 years and a Federal interest rate for water resources projects of 8 1/4 percent. The value of the annual benefits, adjusted to take into account the time value of money, were calculated assuming that development occurs by year 10 of the period of analysis, by year 25, and by year 50. Each calculation assumes that the development occurs in such a way that the benefits increase at a constant rate from year 0 to the year the total calculated benefits are achieved. This analysis does not include the use of an inflation factor.

The value of the discounted annual flood damage reduction benefits is shown below in Table 16. These figures are shown separately from the full, undiscounted benefits mentioned above, since an analysis performed outside of Corps regulations may not require this type of discounting to be performed.

Table 16
Present Value of Future Flood Damage Reduction Benefits

| | Annual Benefits 10% Loss Scenario | Annual Benefits 30% Loss Scenario |
|---|---|---|
| Losses occurring by Year 1 (no discounting) | $19,200 | $55,600 |
| Losses occurring by Year 10 | $13,600 | $39,300 |
| Losses occurring by Year 25 | $ 8,300 | $24,200 |
| Losses occurring by Year 50 | $ 4,600 | $13,200 |

## 7. SUMMARY AND CONCLUSIONS

This report provides a comprehensive investigation into the role of natural valley storage as a method of reducing future flood damages. The report begins by describing the Corps of Engineers mission in flood control and the forty-nine flood control projects constructed in Massachusetts. One of the unique ways of controlling future flooding is through the preservation of natural valley storage areas. These areas are composed of wetlands and floodplains that, due to certain physical features (vegetation, soil, topography, and proximity to the flood source), have the ability to temporarily detain flood waters. This detention capability has the effect of delaying and reducing peak discharges downstream. The Corps of Engineers' Charles River Natural Valley Storage Project in Massachusetts is certainly one of the most unique projects of its kind in the country. A benefit to cost analysis conducted as part of a 1972 Corps' report concluded that preserving (either through purchase or easement) about 8,000 acres of natural storage areas along the Charles River was economically justified.

This report provides a detailed listing of methods for quantifying the costs and benefits of a natural valley storage project. Traditionally, Corps of Engineers' studies have focused on reducing flood damages. This report went further and looked at other benefit categories such as flood insurance savings, recreation, water quality, erosion control, groundwater recharge, commercial fish and wildlife or other products, agriculture, education, and carbon storage. A literature search revealed that there are many methods that theoretically could be used for quantifying these benefits. Traditionally, the Corps of Engineers has focused on damages/costs prevented as its method of benefit calculation. However, there are other methods, at least in theory, that can be used, such as: unit day value, travel cost method, contingent value method, replacement cost method, hedonic price method, and market revenues method.

The report next attempted to display some of these methodologies through a case study. The case study focused on the main stem of the Nashua River in Massachusetts. It was chosen because of the availability of hydrologic data in the area. A hydrologic analysis was performed that identified over 4,800 acres of flood storage lands and determined the effect that the loss of storage would have on flood elevations downstream in Nashua, New Hampshire. About 70% of the storage area, including the FEMA determined floodway, was found to be strictly protected against development. The remaining 30%, composed mainly of forest and cropland along the outer fringe of the storage area, was determined to be the maximum amount of potentially developable land. Ten and thirty percent loss of total storage scenarios were found to incrementally increase downstream flood stages, for the area above Mine Falls Dam, by 0.6 feet and 1.2 feet (for the 100-year event), respectively. The increased flood stages for the area above Jackson Mills Dam was found to be 0.7 feet and 1.7 feet for the two loss scenarios. These increases in stages are a result of increased flood discharge due to the loss of upstream NVS. When analyzing the NVS area for the 30 percent loss scenario some encroachment into the FEMA designated floodway was assumed. This analysis resulted in

flood stage increases of over 1 foot throughout much of the NVS area. These increases are due to the effects of reduced flow area and storage volume along with the resulting increases in flood discharge calculated by the one-dimensional unsteady flow model used in this study.

Examples of calculations to demonstrate development of annual costs and annual benefits were included using gross estimating criteria. Figures developed were intended to illustrate cost and benefit quantification techniques but should not be used as a measure of NVS value within the case study area. That determination would require significant additional investigation. Demonstration level annual costs for land acquisition for the 10 and 30 percent loss scenarios and annual benefits for flood damage reduction, recreation, flood insurance savings, and commercial products are described. Gross values for agriculture, long-term carbon storage, wetland replacement, and energy output were also calculated but due to a lack of information could not be presented on a comparable annual basis.

As a result of the work done during this study several conclusions can be made.

1. From a hydraulic and hydrologic standpoint, natural valley storage can be a very effective means of preventing increases in future flood damages. However, every storage area is unique and must be investigated to determine its capability of temporarily retaining flood waters. An investigation of the river basins within the state should be undertaken to identify those with the best potential for NVS projects.

2. As part of its flood control mission, the Corps of Engineers has and should continue to consider natural valley storage as a viable flood control solution.

3. In an economic analysis of the costs and benefits of preserving natural valley storage areas, the without project condition chosen has a great impact on the estimated costs and benefits of any proposed project. The amount of storage area anticipated to be lost needs to be carefully compared against existing regulatory constraints and an inventory of already preserved lands.

4. Costs for preserving natural valley storage areas are generated using two commonly used methods: outright purchase or instituting conservation restrictions. For a group of land parcels, the latter method can often provide a less expensive project.

5. The traditional use of damages prevented, unit day value, or market value methods are very good measures of flood control, recreation, flood insurance, and commercial fish and wildlife benefits.

6. A literature review revealed that there are several evaluative methods, at least in theory, that can measure other benefit categories such as: water quality, groundwater, agriculture, habitat, education, aquatic food chain support, long-term carbon storage, nonuse and total resource values. The more popular procedures are the travel cost method, contingent value method, replacement cost method, and hedonic price method.

7. As shown in Table 5, in order to measure a particular storage area's total value, several methodologies may need to be employed. When performing this analysis care must be exercised against double counting certain values.

8. Using the Nashua River and its adjacent storage areas in a case study:

- o traditional methods were used to calculate flood damage reduction, recreation, flood insurance, and commercial product benefits.

- o market value, replacement cost, and energy output techniques were used to calculate gross values of agriculture, long-term carbon storage, and total resource value. Sufficient information to convert these gross values to actual benefits was not available.

- o the contingent value and replacement cost methodologies were found to avail themselves well to the calculation of benefits not easily determined such as water quality, groundwater, erosion control, habitat, and total resource value. A lack of available information did not allow the actual quantification of these benefits during the case study, but the methods were described in detail.

- o the contingent value method, depending on how the contingent value survey is designed, can measure several benefit categories at once. Strict control of contingent value surveys is needed to avoid the possible double counting of benefits.

## 8. RECOMMENDATIONS

The preceding work has led to the following recommendations:

- The Commonwealth of Massachusetts should continue to proceed along a path of providing protection of its natural valley storage lands through regulations such as the Wetlands Protection Act and the National Flood Insurance Program. Although this may not completely address the loss of natural valley storage areas, in many cases the proper enforcement of existing Federal and state regulations can avoid the need for outright acquisition of storage lands.

- The research performed as part of this investigation identified several methodologies that can be used to evaluate the economic value of preserving natural valley storage. However, as was demonstrated in the Nashua River Case Study, application of these methods can involve a significant amount of data collection, evaluation, and uncertainty. This report recommends that a preliminary screening effort be conducted to identify significant natural valley storage areas within Massachusetts. This screening effort should include: identification of floodplain areas upstream of large potential damage centers, a determination of each areas' ability to store floodwaters, an evaluation of the areas' potential risk to development, and an inventory of potentially impacted natural resources. Risk to development would include an evaluation of the laws and regulations protecting the areas, the historical amount of these lands being lost to development and an evaluation of current and future development pressures in the region. Any detailed evaluations, similar to those described in this report, should only be conducted for those areas which are shown to be favorable through the screening process.

- There appear to be several different methods (travel cost, contingent value, replacement cost, market value) available for quantifying less traditional benefit values in planning studies. These methodologies should be utilized wherever possible. Corps of Engineers' studies, given the necessary information, could also use these methods to calculate benefits, within the guidelines set forth by regulations.

- The results of the case study identified a lack of transferable information regarding the relationship between water quality and groundwater recharge and the preservation of natural valley storage. Information on this relationship exists in other parts of the country, but that literature and its conclusions are not readily transferrable to this region. Without an understanding of this relationship in the Northeast, a benefit calculation is impossible. Coordination with the United States Geological Survey confirmed this lack of data. Further studies of the relationships of groundwater and water quality to natural storage could be useful to future NVS studies. Based on what is known now it is apparent that each site is unique and needs to be studied on an individual basis.



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# APPENDIX A

# ENVIRONMENTAL LAWS AND REGULATIONS

## FEDERAL AND STATE LAWS AND REGULATIONS AFFECTING POTENTIAL DEVELOPMENT OF NASHUA RIVER WETLANDS AND FLOODPLAINS

### FEDERAL

Clean Water Act, Section 404 (40 CFR 230, 33 CFR 320-330)

Regulates discharge of dredged and fill material into waters of the United States. Waters of the United States include navigable waterways, wetlands, tributaries to navigable waters (including adjacent wetlands, lakes, and ponds), interstate waters and their tributaries, and all other waters, including intermittent streams, not part of a tributary system.

Endangered Species Act (50 CFR 81, 225, 402)

Provides for federal listing and protection of threatened and endangered species.

National Flood Insurance Act (42 U.S.C. 4001-4128)

Authorized the National Flood Insurance Program of 1969 which, through the incentive of Federally backed flood insurance, encourages communities to enact and enforce floodplain regulations.

Executive Order 11988 (40 CFR 6 Appendix A)

Requires federal agencies to avoid adverse impacts associated with the occupancy and modification of floodplains and to avoid support of floodplain development wherever there is a practicable alternative.

Executive Order 11990 (40 CFR 6 Appendix A)

Requires federal agencies to minimize the destruction, loss or degradation of wetlands, and preserve and enhance beneficial values of wetlands.

Fish and Wildlife Coordination Act (16 U.S.C. 661)

Requires federal agencies proposing water resource projects to consult with U.S. Fish and Wildlife Service.

National Environmental Protection Act (40 CFR 1500-1508, 33 CFR 230, 235)

Requires federal agencies to consider environmental consequences of federal actions.

Resource Conservation and Recovery Act (40 CFR 257.3-1, 40 CFR 264.181)

Provides criteria for placement of solid waste disposal sites and hazardous waste disposal sites in floodplains.

## MASSACHUSETTS

Certification for Dredging, Dredged Material Disposal and Filling in Waters (314 CMR 9)

Establishes water quality certification requirements for dredging, dredged material disposal, and filling projects in state waters, including wetlands.

Endangered Species Act (321 CMR 10)

Regulates state listing and protection of threatened and endangered species.

Floodplain and Coastal High Hazard Areas Construction Design Requirements (780 CMR 744):

Provides design requirements for structures built within 100-year floodplains and coastal high hazard areas.

Hazardous Waste Management Facilities Location Standards (310 CMR 30.700 to 30.707)

Regulates placement of landfills, surface impoundments, and waste piles within 500-year floodplains and watersheds of class A surface waters.

Hazardous Waste Wastewater Treatment Unit Standards (310 CMR 30.605)

Requires that treatment units within 100-year floodplain must be floodproofed.

Inland Wetlands Orders (302 CMR 6)

Regulates activities within inland wetlands and provides procedures for establishing encroachment lines along waterways and flood prone areas beyond which no unauthorized activities shall occur.

Interbasin Transfer Regulations (313 CMR 4)

Delineates Massachusetts River basins and provides regulations governing the increased transfer of surface and groundwater between basins.

Massachusetts Environmental Protection Act (301 CMR 11)

Requires environmental review of activities carried out, funded, or permitted by state agencies.

Metropolitan Watershed Protection Act (M.G.L. c. 92)

Regulates activities within Metropolitan District Commission water supply watersheds. [These include the upper reaches of the Nashua River that have been impounded in Clinton, MA to form the Wachusett Reservoir.]

River Protection Act (pending legislation)

If enacted, this law would establish a statewide development setback of 150 feet from rivers and streams, except in densely developed areas where the setback could be as little as 25 feet.

Scenic and Recreational Rivers Orders (302 CMR 3)

Provides regulations for designation and protection of scenic and recreational rivers and streams. [The North Nashua River between Route 2 and the New Hampshire border is a locally designated scenic and recreational river.]

Solid Waste Sanitary Landfills Location Standards (310 CMR 19.02)

Provides location standards for sanitary landfills. Placement of landfills in wetlands or floodplains is generally prohibited.

Surface Water Quality Standards (314 CMR 4.00)

Sets water quality standards for state waters and antidegradation provisions.

Waterway Regulations (310 CMR 9)

Regulates placement of structures or fill and dredging in state waterways and tidelands.

Wetlands Protection Act (310 CMR 10.00-10.99)

Regulates activities affecting wetlands, surface waters, and land subject to flooding.

## NEW HAMPSHIRE

Alteration of Terrain (N.H. Administrative Rules Env-Ws 415.03)

Requires permit when an contiguous area of 100,000 square feet or more will be disturbed. Focus is on control of erosion and stormwater runoff.

Endangered Species Act (N.H. Code of Administrative Rules Fis 1000)

Regulates state listing and protection of threatened and endangered animals.

Hazardous Waste Facilities Siting (HE-P 1905 s. 1905.08(g and h))

Limits placement of landfills, treatment and storage facilities, and disposal facilities within floodplains, near streams and lakes, and within watersheds of class A surface waters.

Land Application of Sludge and Septage (He-P 1901.05(d))

Prohibits stockpiling of sludge or septage within 100-year floodplain, and sludge spreading on poorly drained or seasonally flooded soils.

Native Plant Protection Act (RSA 217-A:9)

Regulations protecting state listed threatened and endangered plants.

Radiation Control Rules (He-P 2067, s. 2067.01 - 2067.11, Appendix P)

Prohibits disposal of low level radioactive waste within 100 year floodplain.

Solid Waste Facility Standards (He-P 1901.05 (a, i, or j))

Requires that facilities or practices located within floodplains not effect the base flood.

Wetlands Protection Regulations (N.H. Administrative Rules Env-Wt 100 through Env-Wt 800)

Regulates activities in wetlands and surface waters.

# APPENDIX B

# WATER QUALITY EVALUATION

APPENDIX B

MASSACHUSETTS NATURAL VALLEY STORAGE
INVESTIGATION - SECTION 22

WATER QUALITY EVALUATION

TABLE OF CONTENTS

WATER QUALITY EVALUATION
MASSACHUSETTS NATURAL VALLEY STORAGE INVESTIGATION
SECTION 22

1. INTRODUCTION

The purpose of this investigation is to research and discuss methodologies to quantify the economic benefits of natural valley storage as a flood control alternative as compared to structural solutions. This Water Quality Evaluation specifically identifies potential water quality, erosion control, and groundwater recharge benefits gained from the preservation of natural valley storage. The evaluation further identifies methodologies used to quantify the value of these benefits. These methodologies are evaluated in terms of their effectiveness in applying them to Massachusetts natural valley storage areas.

Natural valley storage is the preservation of wetlands and flood plains which provide significant flood water retention. Wetlands and flood plains that provide ample storage cause attenuation of flood peaks. Water quality constituents seem to attenuate with flood peaks, lessening the shock of nutrients entering waterways from storm water runoff. Natural valley storage also induces settling of suspended materials and often decreases bank erosion, as flow through wetlands and over flood plains is relatively lethargic. Some wetlands and flood plains can also increase groundwater recharge, depending on their hydrogeological characteristics. Wetlands provide additional benefits in that they usually improve the quality of water passing through. However, some wetlands introduce additional nutrients to the outflowing waters, especially during the winter months. The ability of a wetland to improve water quality characteristics depends on the season, its hydrologic characteristics, vegetation, soil characteristics, and microbial community.

The potential economic value of wetlands and flood plains to improve water quality, erosion control, and groundwater recharge is difficult to estimate. Most methodologies for evaluating these benefits are based on costs to society of providing the same amount of water quality, erosion control, and groundwater recharge improvements using alternative sources or technologies.

2. WATER QUALITY

a. Benefits

Water quality improvements induced by natural valley storage include settling of suspended material, and usually reductions in or storage of organics, nutrients, and metals. Both floodplains and wetlands promote

settling of suspended solids due to their gentle slopes and low flow-through velocities. The slower the water movement and longer the hydraulic detention times of these storage areas, the more suspended materials settle, promoting higher quality waters. Suspended sediments adsorb metals, nutrients, and organics, and these constituents may be temporarily immobilized or permanently lost when the sediments settle. The sediments sometimes resuspend during disturbances such as storms, or release the adsorbed materials reintroducing them into the water. However, the accretion rate of sediments may prevent resuspension causing permanent immobilization. The amount of settling and rate of accretion is highly site and time specific, depending on hydrologic characteristics, soil types, topography, water quality, vegetation, etc.

A wetland can also improve water quality through biological and chemical processes in its soils and plants. Wetland sediments are usually anaerobic due to their continuously inundated state. Nitrification and denitrification processes in the water column and anaerobic sediments remove most nitrogen from overlying waters. Plants take up nitrogen, and to a much lesser degree, phosphorus, usually at significant rates during the growing season. However, a portion of these nutrients are released upon decay. Metal and organic contaminant loads of influents undergo change as they pass through wetlands as well. A wetland ecosystem may temporarily store, utilize, export, or transform these constituents due to its complex chemical and biochemical environment. A wetland that takes in or transforms constituents purifies the water as it passes through. On the other hand, a wetland that exports more constituents than it takes in contributes to a poorer water quality effluent. A wetlands ability to act as a source or a sink depends on hydrologic characteristics, vegetation, sediments/soils, and microbiota (Elder, 1987).

Many studies have been conducted indicating some wetlands act as nutrient sinks. Tilton et al. (1978) studied the role of wetlands in improving water quality and found nitrate and nitrite nitrogen, total dissolved phosphorus, and ammonium removals of 99, 95, and 71 percent, respectively. Furthermore, they found decreases in turbidity and suspended solids between inflow and discharge stations. German (1989) found a 36 percent decrease in nitrogen and 33 percent decrease in phosphorus by a natural wetland system. The Corps of Engineers Waterways Experiments Station compiled data from several wetland studies (some from Massachusetts) in the Northeastern United States and found cases where wetlands acted as sources, sinks, and transformers of nutrients and heavy metals depending on the particular wetland system.

Since many wetlands act as nutrient sinks, they have been successfully used to treat secondary effluent, storm water, and agricultural runoff. Removals of 60 to 90 percent suspended solids and 40 to 90 percent nitrogen from secondary effluent have been observed in various studies (Crites, 1988). Kadlec and Alvord (1989) demonstrate the Houghton Lake wetland treatment system in Michigan consistently treated over 400,000 $m^3$/yr of secondary municipal wastewater to 96 and 97 percent removals of total phosphorus and ammonium nitrogen, respectively, over an 11-year period.

b. Methodologies

(1) Replacement Cost Methodology. Replacement cost methodology evaluates water quality benefits gained from natural valley storage by equating them with the cost of a replacement project, providing the same service to society. Water quality services that wetlands can perform include tertiary treatment of secondary effluent and treatment of storm water and/or agricultural runoff. Most reviewed literature focuses on wetlands, and it appears that few researchers investigated water quality benefits derived from nonwetland natural valley storage areas. Detailed studies have been conducted to determine a wetland's ability to assimilate nutrients, or perform tertiary treatment. The amount of nutrients removed or absorbed by a wetland is generally determined by comparing nutrient concentrations from inflow and outflow data.

Water quality benefits derived from the replacement cost technique are usually used with other techniques to provide an overall, holistic value of the natural valley storage area. Gosselink, among other researchers, incorporated replacement costs in a technique called energy analysis, which is a holistic approach for estimating a wetland's worth. It establishes the social value of the wetland in terms of the amount of energy it provides. For this analysis, Gosselink identified four groups of benefits for which dollar values were estimated, one group was sewage waste assimilation (Luzar and Gan, 1991).

Using this analysis, Gosselink determined that the per acre capitalized value of sewage waste assimilation performed in a particular wetland is $50,000 (1974 costs), based on the alternative cost of conventional tertiary treatment (Luzar and Gan, 1991). In 1973, Gosselink, Odum, and Pope converted sewage effluent loading results of phosphorus into an annual dollar value of $480 per acre by applying an alternative cost of $1.20 per pound of phosphorus removal by conventional methods (Park and Batie, 1979). Using this same technique, Bender and Correll converted their effluent loading results to an annual dollar value of $158 per acre of wetland for phosphorus removal (Park and Batie, 1979).

Luzar and Gan (1991) summarize, in detail, the limitations involved by using the replacement cost methodology (as part of the energy analysis), concluding that it tends to overestimate the value of wetlands by not considering factors such as human demand for natural system services. In other words, society must be willing to pay, at a minimum, the cost associated with the alternative method for the particular service (water quality improvement) the wetland provides (Park and Batie, 1979). If surface water discharge criteria requires only secondary treatment of wastewater, then a wetland receiving secondary discharge and functioning as a tertiary treatment facility may not be highly valued by the public for that function. Another significant limitation is that cost figures identified above are only reliable for the specific wetland studied, and cannot be generalized to apply to other wetlands or natural valley storage areas. Valuations are highly site specific, since the degree of sedimentation and assimilation of nutrients, organics, and metals varies

greatly for each different natural valley storage area (Park and Batie, 1979). Extensive data collection at inflow and discharge stations would need to be performed to apportion water quality benefits incurred by each different storage area. Park and Batie (1979) identify another limitation warning that "only those wetlands plots that are actually used for nutrient assimilation have any value for that purpose." A wetland should not be valued as a tertiary treatment system if it is not being used as one. Finally, the replacement cost technique is limited by the complexity of wetland ecosystems, which are quite complicated and not entirely understood (Luzar and Gan, 1991).

The replacement cost methodology has been used to value water quality benefits of wetlands in other ways. Tilton et al. (1978) compared costs of nutrient removal from secondary wastewater effluent to tertiary levels using spray irrigation to the costs of treating the effluent using a wetland. Assuming 1978 prices, the present worth for a spray irrigation system was estimated to be $20,299 compared to $11,197 for purchasing and maintaining treatment in a natural wetland. Limitations of this technique mirror those mentioned above, except Tilton evaluates a wetland's ability to assimilate waste even if it is not currently being used for that purpose. He assumes the wetland must be purchased, wastewater transported, and treatment system maintained to compare its value to other tertiary treatment facilities. Tilton mentions an additional concern regarding the use of existing wetlands to treat wastewater: Regulation may prohibit the use of natural wetlands to treat secondary effluent.

Tilton et al. (1978) also suggest that the function of wetlands as natural storm water runoff collection and treatment systems could be considered in assessing a wetland's worth relative to the cost of collecting and treating storm water runoff by manmade systems. When wetlands are filled, they no longer have the capacity to collect and treat storm water runoff. The runoff would have to be diverted to storm sewer pipes and rerouted to an alternative treatment site, for which Tilton estimated the 1978 discounted capital cost to be $9,237. This compares favorably to the no cost alternative of a wetland which collects and treats storm water runoff naturally. Besides diverting storm water runoff, land use practices can also be incorporated to reduce runoff from agricultural land to lessen sediment and nutrient loading to a waterway. Water quality improvement costs can be estimated by determining the net returns to farmers who apply these land use practices (Park and Batie, 1979). If a wetland treats secondary effluent along with runoff, the combined benefits give the wetland area even greater value.

(2) <u>Hedonic Price Technique</u>. This methodology is based on the assumption that people will pay for a wetland if it borders their property (between their property and the shoreline) provided it is aesthetically pleasing. The value of the wetland depends on physical characteristics such as setback, proximity, and aesthetic quality, as well as the local economy. Allen and Stevens present this methodology in their report entitled, "Use of Hedonic Price Technique to Evaluate Wetlands" (1983), stating that it "relies on observed behavior to value non-market goods." In other words, people would be willing to pay for this wetland to prevent

it from being destroyed and, therefore, destroying their view. This methodology indirectly assesses the worth of a wetland's water quality benefits assuming that the cleaner a water is, the more people will value it.

Hedonic pricing tends to underestimate the value of certain wetland areas according to Allen and Stevens (1983) because of the following limitations. First, the proper economic model must be used to evaluate the area. Second, each evaluation is site specific, and cannot be generalized due to the great diversity in wetlands and local economies. Third, the home buyer and seller must be aware of the wetland areas value. Finally, certain externalities may fail to be incorporated into the house pricing market, such as a water fowl breeding area.

3. EROSION CONTROL

a. Benefits

Natural Valley Storage improves downstream erosion control by attenuating peak floods, reducing the depth and velocity of the floodflow. Wetlands also reduce local erosion by sediment stabilization, wave energy dissipation and velocity reduction provided by plants. These attributes protect the adjacent shorelines from erosion as well. One problem with assuming erosion control is a direct benefit of wetlands, however, is that most shoreline wetlands only develop and remain on shores with low wave energy and velocity, where erosion is not usually a problem to begin with.

It appears that very little research regarding natural valley storage effects on erosion control has been performed. Owens (1980) conducted a study in Chesapeake Bay and found that the wetland vegetation and relatively flat configuration appear to dissipate incoming wave energy, protecting the shoreline located behind the wetlands.

b. Methodologies

(1) Damage Cost Methodology. Owens (1980) evaluated a wetlands worth as a means of erosion control to prevent flood damages in terms of the value of waterfront property. He found the value of a waterfront lot decreases as its erosion rate increases. He first determined the average income a person investing in a waterfront lot would receive over time. He states that "the value of income expected from a lot with a wetlands area lying in front of it was found to be higher than a lot without a wetlands area." Using this same methodology, Scodari (1990) suggests erosion control benefits can be valued based on the cost of removing sediment from a navigable waterway.

Limitations of this methodology are similar to those of the replacement cost methodology as it is highly site specific. In addition, Scodari (1990) states "it does not consider social preferences for wetland services or individuals' behavior in the absence of those services." If a wetland is dredged eliminating its erosion control benefits, property

owners may be willing to pay for a structural solution to prevent potential flood damages. In this case, the cost of potential flood damages (incurred assuming the wetland is removed) used to determine the wetland's worth may greatly exceed the cost of this structural solution. Consequently, damage cost methodology would overestimate the wetland's worth. Another major limitation is that this methodology only applies when dredging (removing) the wetland is being proposed. If filling the wetland were the proposed alteration, erosion control of the adjacent upland would no longer be a concern.

(2) Replacement Cost Methodology. This methodology, used previously for water quality benefits, assumes the value of a wetland would be worth the cost of an alternative method of erosion control. Owens (1980) calculated the cost of bulkheading as an alternative and found naturally occurring wetlands to be a less expensive form of erosion control. This methodology could also be applied using other structural alternatives such as stone protection.

Replacement costs usually place a lower value on wetlands than the damage cost methodology. Major limitations of the replacement cost technology for erosion control are as follows: (a) it is highly site specific, and (b) it only applies if the wetland is going to be dredged and not filled in.

4. GROUNDWATER RECHARGE

a. Benefits

Natural valley storage can recharge groundwater provided optimum soil conditions and surficial geology prevail in the particular wetland or flood plain. Each natural valley storage area must be studied carefully to determine the soil and groundwater conditions indicating if the area recharges the groundwater or if the groundwater is discharging water to the surface. Groundwater recharge/discharge may vary seasonally, and water supply wells can also affect the recharge/discharge capacity of an aquifer depending on water usage. Groundwater recharge from wetlands is expected to be less than from other natural valley storage areas, as wetland soils are usually less permeable than soils associated with groundwater recharge (Larson, 1990). However, according to Larson (1973), at least 60 Massachusetts cities and towns have municipal water production wells in or very near wetlands.

b. Methodologies

Replacement Cost Methodology can be used if a wetland or flood plain recharges to an aquifer that could be used for public or private water supply. It relates the loss of natural valley storage groundwater recharge benefits to the cost of a replacement water supply. Gupta and Foster used this technique to estimate groundwater recharge benefits for inland freshwater wetlands in Massachusetts during a study he conducted from 1973 to 1975 (Tilton et al. 1978). They determined the cost of pumping and delivering groundwater from a wetland aquifer compared to the

cost of water supplied and delivered by a water purification plant in terms of dollars per acre. The difference in cost was $202.38 per acre (1972 costs), and is the net worth of the wetland as a groundwater supply source. Using the same approach, Larson (1976) estimated the annual water supply benefits of a typical inland wetland in Massachusetts, producing 1 million gallons per day (for water supply), to be $2,800 per acre (1972 costs). This estimate was based on studies of well fields located in the northeast United States having yields ranging from 300 to 1,400 gallons per minute and depths of 75 to 200 feet. It was also based on alternative water sources supplied and distributed by the Metropolitan District Commission.

Similar to other applications of replacement costs, one major limitation is that the estimates are site specific. In order to use this methodology to evaluate a particular natural valley storage area's groundwater recharge benefits, the area would have to be studied to determine if it recharges the groundwater and to what degree recharge occurs. Furthermore, the groundwater must be of high enough quality to serve as a water supply source. Another problem with using this method is that the public must need the benefits. In other words, if a flood plain groundwater aquifer is not currently being used as a water supply, then society may not find its value to be equivalent to the cost of an alternative water supply.

## 5. DISCUSSION

Although the literature suggests significant water quality, erosion control, and groundwater recharge benefits can be gained from natural valley storage; these benefits are extremely difficult to quantify. Results of this investigation indicate that three different approaches have been taken to evaluate benefits provided by these services. Moreover, most research for all approaches focused on wetlands, and little research was found dealing with other forms of natural valley storage. The most widely used methodology seems to be the replacement cost technique.

A common limitation for all three methodologies is that they are site specific, and cannot be generalized to apply to each different natural valley storage area. Consequently, significant data collection and site investigation should be performed for each different storage area in order to apply any valuation methodology. Another limitation which applies to all methodologies is that individual values estimated for each service cannot always be added to obtain a net value for the storage area. Costs are often at odds with one another, or with other natural valley storage benefits. For instance, benefits gained from a wetland that accepts secondary treatment cannot be added to benefits from groundwater recharge because acceptable drinking water standards are required. Another example is that a coastal wetland cannot be evaluated simultaneously for its sewage treatment and shellfish production capabilities.

Estimating the value of a natural valley storage area is difficult because most people are not aware of ecologic benefits it provides society. Aside from potential water quality, erosion control and

groundwater recharge benefits, other benefits can be gained such as flood control, recreation, fish and wildlife protection, etc.. All benefits obtained from a natural valley storage area should be considered to determine its total holistic value.

## 6. APPLICATION TO NASHUA RIVER BASIN

Application of replacement cost, damage cost, and hedonic price techniques for estimating water quality, erosion control, and groundwater recharge benefits derived from preservation of natural valley storage areas in the Nashua River Basin would be an extremely complex task, and is beyond the scope of this project. Significant data collection and evaluation for each individual storage area would be required in order to use any of these techniques. In addition to hydrologic information, data collection would include, at a minimum, measuring water quality constituents in inflows and outflows and groundwater monitoring. Data would have to be collected over a one-year period to account for seasonal variations in effluent water quality and groundwater recharge or discharge levels. Additionally, a detailed investigation of each storage area site and its watershed land use would have to be conducted to determine the following: its use as a storm water collection and treatment system, its potential for providing tertiary treatment, if any water supply wells draw from aquifers that are hydraulically connected to the site, and finally, setback distances of properties located near the area with potential erosion control or aesthetic benefits.

## 7. CONCLUSION

Natural valley storage can often provide significant water quality, erosion control, and groundwater recharge benefits. The amount of these benefits varies widely with each different flood plain storage area, as these areas are generally extremely complex ecosystems such as wetlands. Water quality benefits include sediment control or settling of suspended solids (increased sedimentation), and usually a reduction in nutrients, organics, and metals. Natural valley storage can sometimes provide groundwater recharge, increasing the yield of water supply aquifers. Finally, erosion control benefits can be gained because water travels more slowly over flood plains and through wetlands, and wave energy is dissipated due to vegetation and lower water depths.

Evaluation of benefits obtained from natural valley storage is necessary in order to perform sound resource management of these natural ecosystems. The difficulty in evaluating the worth of these resources lies in quantifying their value to mankind. Evaluation methodologies presented in this investigation include replacement cost, hedonic price, and damage cost techniques. The replacement cost methodology is used for water quality, erosion control, and groundwater recharge benefits and is based on the assumption that people will be willing to pay for an alternative technology that provides the same service. The hedonic price technique is used to estimate a homeowner's value of a wetland based on its proximity and setback distances, and aesthetic appeal. The damage cost methodology is used for erosion control benefits, and assumes people will pay more money for property located behind a shoreline wetland since

it provides shoreline erosion control and protects their property. Many other techniques have been used to evaluate natural valley storage areas, but they are not mentioned in this investigation because they are not directly related to water quality, erosion control, or groundwater recharge benefits.

Since natural valley storage areas vary greatly, application of evaluation methodologies is highly site specific. It appears that the only way to utilize these methodologies for an individual storage area is to collect as much data as possible and study the site in detail. Possible recommendations the Commonwealth of Massachusetts may want to consider to prepare for natural valley storage area evaluations are: (a) synthesize all existing available data for natural valley storage areas in the State, (b) identify storage areas which provide the greatest benefits, or rank all areas in terms of the types of benefits or potential benefits they provide, (c) if enough funds are available, set up a monitoring program to determine constituent loads and discharges for selective storage areas, and (d) at the very least, organize a systematic approach for evaluating the benefits provided by natural valley storage areas.

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# APPENDIX C

## HYDROLOGY: OVERVIEW OF NATURAL VALLEY STORAGE AND CASE STUDY ANALYSIS

APPENDIX C

MASSACHUSETTS NATURAL VALLEY STORAGE
INVESTIGATION - SECTION 22

PART I
OVERVIEW OF NATURAL VALLEY STORAGE

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## INTRODUCTION

New England Division is conducting a Natural Valley Storage investigation for the Commonwealth of Massachusetts under the authority contained in Section 22, Planning Assistance to States Program. The goal of the study is to research and discuss methodologies to quantify, in economic terms, costs, and benefits of natural valley storage (preservation of wetlands and floodplains which provide significant floodwater retention). Such preservation could be viewed as a flood control alternative to any required future structural solution.

There are two parts to this hydrologic review of natural valley storage. Part I includes a general description of natural valley storage (NVS), watershed characteristics, flood control effectiveness of NVS, impacts of loss of natural valley storage, and evaluation methods. Part II discusses the case study completed for the Nashua River to illustrate how some techniques discussed in Part I can be used to evaluate natural valley storage.

MASSACHUSETTS NATURAL VALLEY STORAGE
SECTION 22 INVESTIGATION

PART I
OVERVIEW OF NATURAL VALLEY STORAGE

## 1. GENERAL DESCRIPTION

Natural valley storage areas consist of wetlands, floodplains, and overbank areas of a river where floodflows are temporarily stored before being conveyed downstream. During flood periods when discharges and stages within these areas are increasing, water flows into the natural valley storage areas temporarily until floodwaters recede. The effect of this temporary storage is to lag and reduce the flood peak as it progresses downstream (see section 4.a.(4) for an example). This may prolong the period of floodwater flow, but reduces the discharges and flooding stages downstream.

Another important function of natural valley storage is its ability to convey water. Flood conveyance capacity is greater in deeper and wider channels and adjacent areas, such as floodplains and wetlands. Wetlands which contain heavy vegetation growth up to the level experienced during floods have little flood conveyance ability, since the stage required to better convey floodflows would be above the vegetation height. The greater the conveyance capacity, the lower the flood elevations along the stream's reach. Wetlands closer to the channel of a stream, especially those adjacent to high gradient streams with narrow floodplains, have greater conveyance capacity, while backwater wetlands have more flood storage capacity (Kusler, 1987).

There are many different types of wetlands with varied hydrologic characteristics, which make generalization of wetlands difficult. For example, the type and density of wetland vegetation affects water velocities which in turn affect flood conveyance and storage capabilities. The shape, size, and depth of a wetland are also major factors in flood conveyance and can be changed by impacts to the watershed such as tree cutting, draining, filling, and urbanization. These changes can increase sediment loadings and runoff. High sedimentation can fill wetlands which also affects flood conveyance and storage.

## 2. WATERSHED CHARACTERISTICS

Runoff characteristics of a watershed can be significant in determining flooding. Infiltration is a factor affecting runoff. Different soil types have different infiltration capabilities. The sand and gravel types of soil have high rates of water transmissibility and lower runoff potential, while the clay type soils have low rates of water transmissibility and higher runoff potential.

Low gradient surfaces with high roughness coefficients and high absorptive capacities have relatively low conveyance capabilities and

relatively high storage, while high gradient and impermeable surfaces (e.g., pavement) quickly convey water from higher to lower elevations and store relatively little. Areas that have a high initial water content usually produce very quick runoff.

Watersheds having significant natural valley storage often have sluggish runoff as compared to paved areas which have accelerated runoff as noted in the Charles River Watershed Natural Valley Storage study (Corps of Engineers, 1976). Runoff flows quickly from paved, lower, urbanized areas into the Charles River, raising water levels and accelerating flows. However, in the less developed upper watershed, natural valley storage areas and flat stream gradients, with significant wetlands, hold excess floodwaters making runoff from these areas sluggish (Doyle, 1987).

The amount of natural valley storage area within a basin can be considered a characteristic of that watershed. The more natural valley storage in a watershed, the greater the reduction in floodflows due to available storage. Comparing the Charles River Basin and the adjacent Blackstone River Basin illustrates the effect of natural valley storage on reducing floodflows. The Charles River Basin has much more natural valley storage in comparison to the Blackstone. During the 1955 flood, its peak discharge was only 17.5 cubic feet per second per square mile (csm) and the Blackstone River Basin was 121 csm. Figure C-1 shows the difference in hydrographs; the Blackstone peaks fast and high due to relatively small amounts of storage, while the Charles peaks slow and low.

## 3. TYPES OF STORAGE AREAS THAT CAN BE EVALUATED

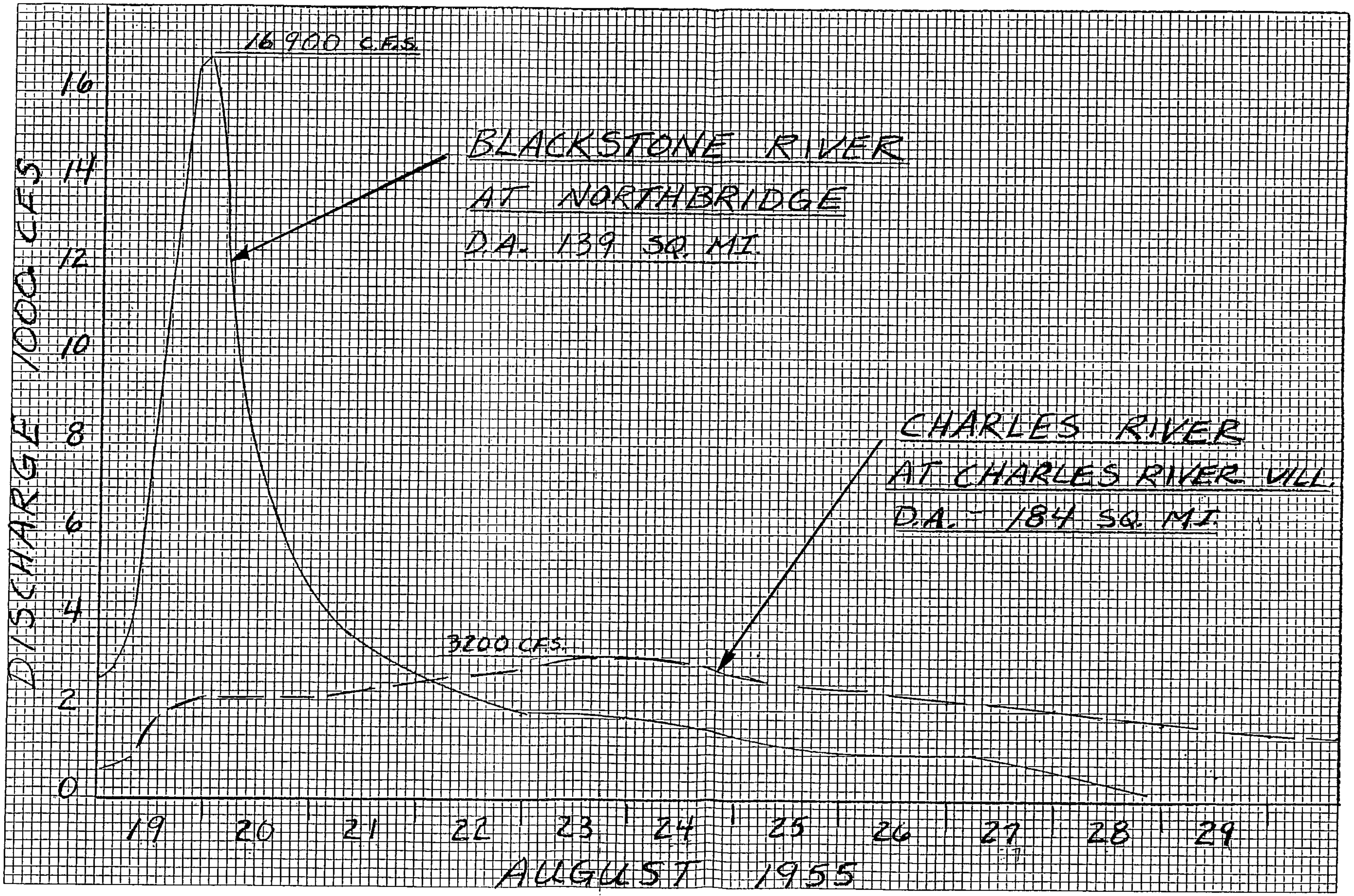
Some individual storage areas act like reservoirs. Some examples are: ponds, lakes, wetlands, and swamp areas that have hydraulic controls (i.e. dams, constricted discharge points) which allow them to store the water. Floodplains act as storage areas along the river. Floodwaters enter the floodplain when the river exceeds its banks. In many cases these areas do not act specifically like reservoirs. Floodplains hold water, but also convey water downstream. They act more like part of the river than a reservoir. There are engineering techniques to evaluate both types of storage areas.

## 4. EVALUATING STORAGE AREAS

a. <u>General</u>. It is not easy to generalize how to evaluate natural valley storage for every watershed. Each basin is different, and depending on its characteristics and topography, the evaluation process varies. The following are two evaluation methods. The Nashua River Watershed Case Study (Part II of this report) illustrates techniques similar to that discussed here in section c.

b. <u>Storage Areas That Act Like Reservoirs</u>. These areas may be selected based on size, drainage area, and effectiveness of storing floodwaters.

(1) <u>Area Capacity</u>. A relationship between elevation, area, and storage capacity needs to be determined. In the Charles River Study, for example, 2-foot contour maps were used and the area of storage was




Blackstone River VS Charles River for the 1955 flood.



FIGURE C-1

computed at different elevations. This information was used to determine area-capacity relationships (see Figure C-2).

(2) Estimating Flood Inflow. Unit hydrographs for the basin of each storage area can be developed by basing the unit hydrograph's characteristics on the basin's size and slope and by studying their historic timing and response. Flood inflow is estimated by applying appropriate excess rainfall to the unit hydrograph for each storage area.

(3) Outlet-Discharge Rating. For each storage area an outlet-discharge relationship (stage-discharge curve, see Figure C-3) is developed. During the Charles River Study, for example, these relationships were based mostly on field inspections and hydraulic computations using historic high water information as a guide. Available USGS ratings at gages or flood profiles from Flood Insurance Studies can also be used, if applicable.

(4) Elevation-Storage-Discharge Relationship. By developing a relationship between elevation, storage, and discharge, inflow hydrographs can be routed through storage areas. There are several techniques including: the "Modified Puls" and "Lag-Average".

The "Modified Puls" reservoir routing method, via the HEC-1 model, routes the hydrographs through the storage areas. This method involves inputting a volume/outflow relationship and specifying initial conditions of either stage, storage, or outflow.

The "Lag-Average" technique, used for the Charles River Watershed, involves coefficients related to reach length, slope, and relative amounts of apparent storage. This technique is used principally for main river flows.

Figures C-4 and C-5 show 1955 flood inflow and routed outflow hydrographs for two storage areas from the Charles River Study and illustrate the concepts discussed in section 2. Figure C-4 describes an area with relatively minor storage; the two hydrographs are similar (i.e., outflow almost equals inflow; minor amounts of floodflows are stored). An area with a large amount of storage has a very different look (see Figure C-5); an early, high peaked inflow hydrograph and a lagged, low peaked outflow hydrograph (i.e., much of the water is being stored by the storage area or "reservoir"). Shaded area "A" represents the volume of water going into storage and area "B" equals that coming out of storage. When the total inflow has flowed out of the basin, area "A" equals area "B". As illustrated, temporary storage results in the reduction and lag of the peaks between inflow and outflow hydrographs.

(5) Calibration. The storage outflows and local inflow hydrographs are appropriately combined and routed downstream. The routing models are considered calibrated if the resulting downstream hydrograph's timing and magnitude compare reasonably with that of an observed hydrograph from a downstream gage. Figures C-6 and C-7, for example, show the computed and observed hydrographs for the 1955 flood at the Charles River Village and Waltham gages from the Charles River Study.

(6) Loss of Storage Effects. For the Charles River Study, selected storage areas were considered lost by assuming future outflow will equal inflow and not performing any storage routing though the areas. Final effects of the loss of selected natural valley storage areas on the 1955 flood at two locations are shown in Figures C-8 and C-9. The hydrographs without storage are higher and generally peak faster than those with storage.

c. River Reaches With Off-Channel Storage. River reaches with considerable floodplains, acting as storage areas and having hydraulic conveyance capabilities, need to be evaluated differently. Some items that should be considered are hydrologic storage and hydraulic flood conveyance capacity as well as flood elevations. A river reach with off-channel storage has a water surface profile that is sloping (see example from Neponset River study, Figure C-10), while a reservoir-like storage area assumes a level water surface.

(1) Data Needed For The Evaluation. Cross sections representing the channel and overbank off-channel storage are necessary for the reach of river to be evaluated. Sometimes this reach geometry data is available in backup files of Flood Insurance Studies. USGS gage data for estimating inflows and checking outflow accuracy is desired, if available. High watermark data is useful for calibration purposes, especially if gage data is not available.

(2) Estimating Inflows. Initial inflows at the upstream end of the reach are determined from available data. For the Neponset River Study the two river branches above the reach had USGS streamflow gages; therefore, runoff hydrographs for each branch were developed and combined to estimate total inflow.

Local inflows need to be estimated for tributary areas. One possible method is developing unit hydrograph parameters based on known areas with similar watershed characteristics. Using these parameters, resulting runoff hydrographs for the local areas can be developed. Figure C-11 shows example hydrographs developed for the Neponset River Study.

(3) Analyzing Hydraulic Flow Conditions and Storage Effects. Generally, a dynamic unsteady flow model is used for routing the flood hydrographs through the river reach. An unsteady flow model allows for consideration of hydraulic conveyance and storage capacity. Output for such a model usually illustrates attenuation of the flood hydrograph and provides the resulting stages, discharges, and timing of the flood as it progresses downstream.

(4) Calibration. The model is calibrated on its ability to reproduce historic flood levels and observed downstream gage hydrographs, if available.

(5) Analyzing Loss Of Storage Effects. Once the model is calibrated, several floods may be analyzed showing existing conditions and modified conditions involving percentage of storage loss which represent

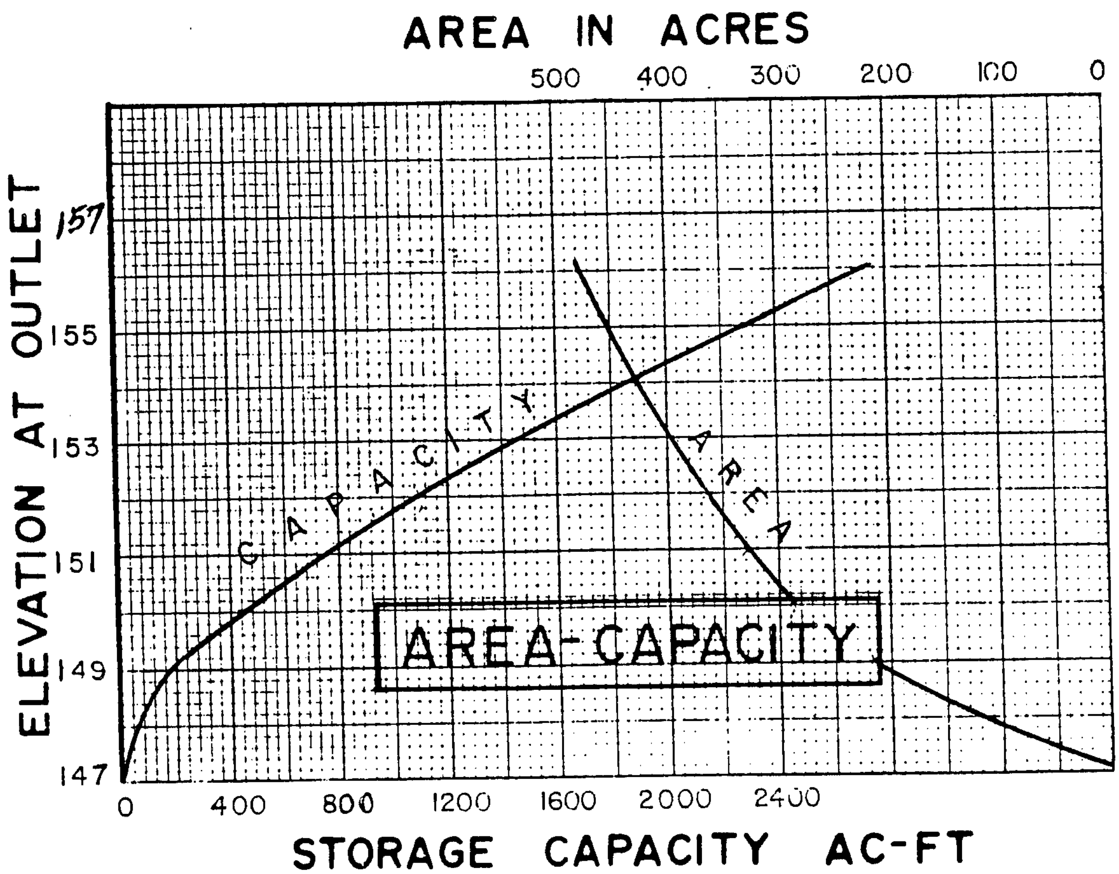



FIGURE C-2 Area-capacity relationship for storage area "K" from the Charles River Study.

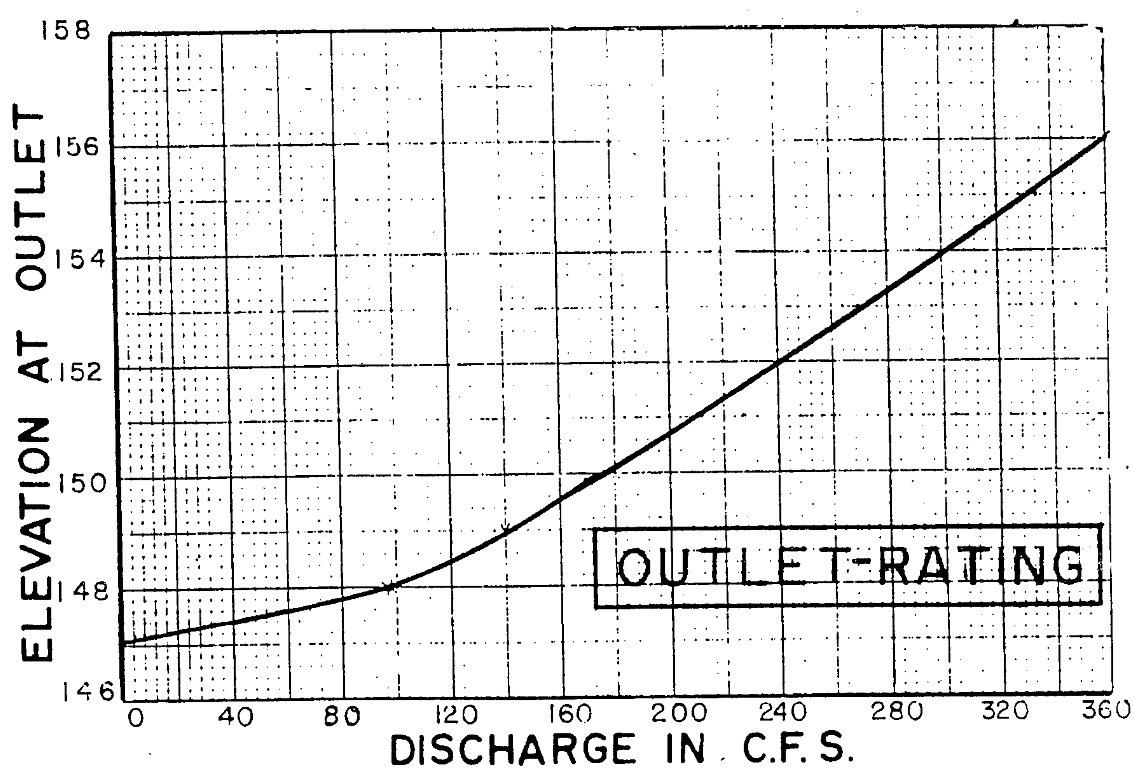



FIGURE C-3 Outlet-rating relationship for storage area "K" from the Charles River Study.

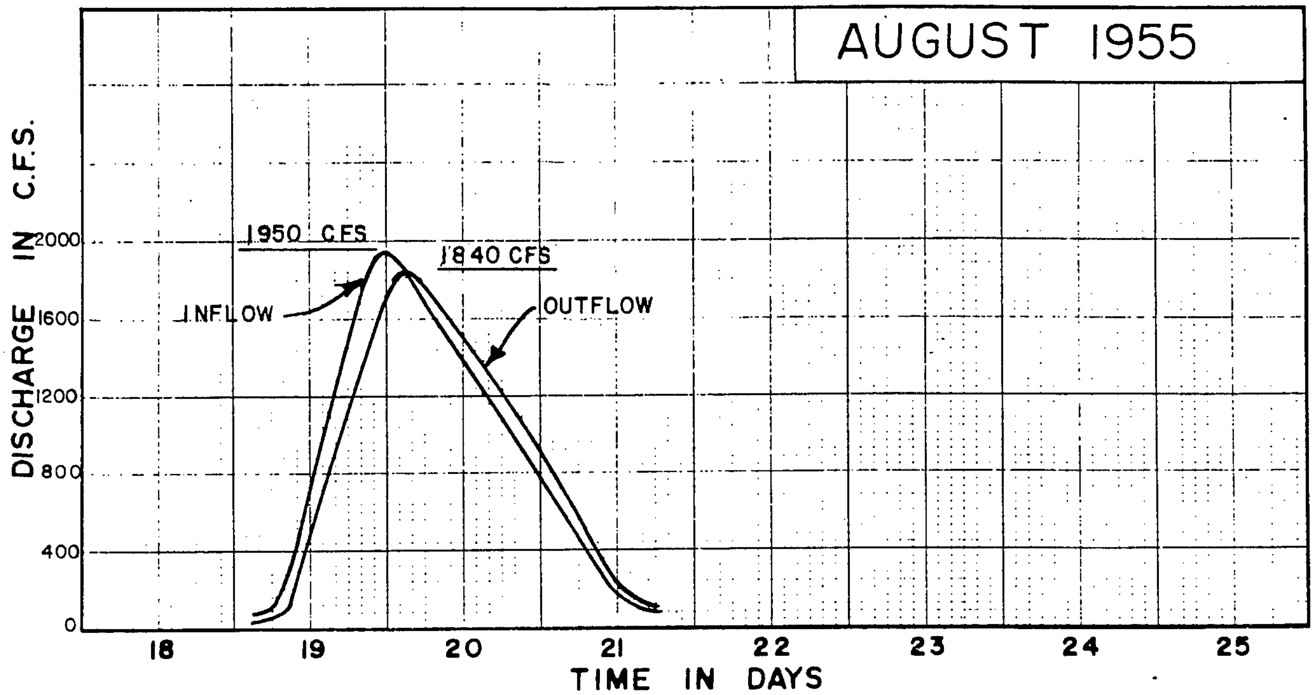



FIGURE C-4 Inflow and outflow from storage area "S" during the 1955 flood from the Charles River Study.

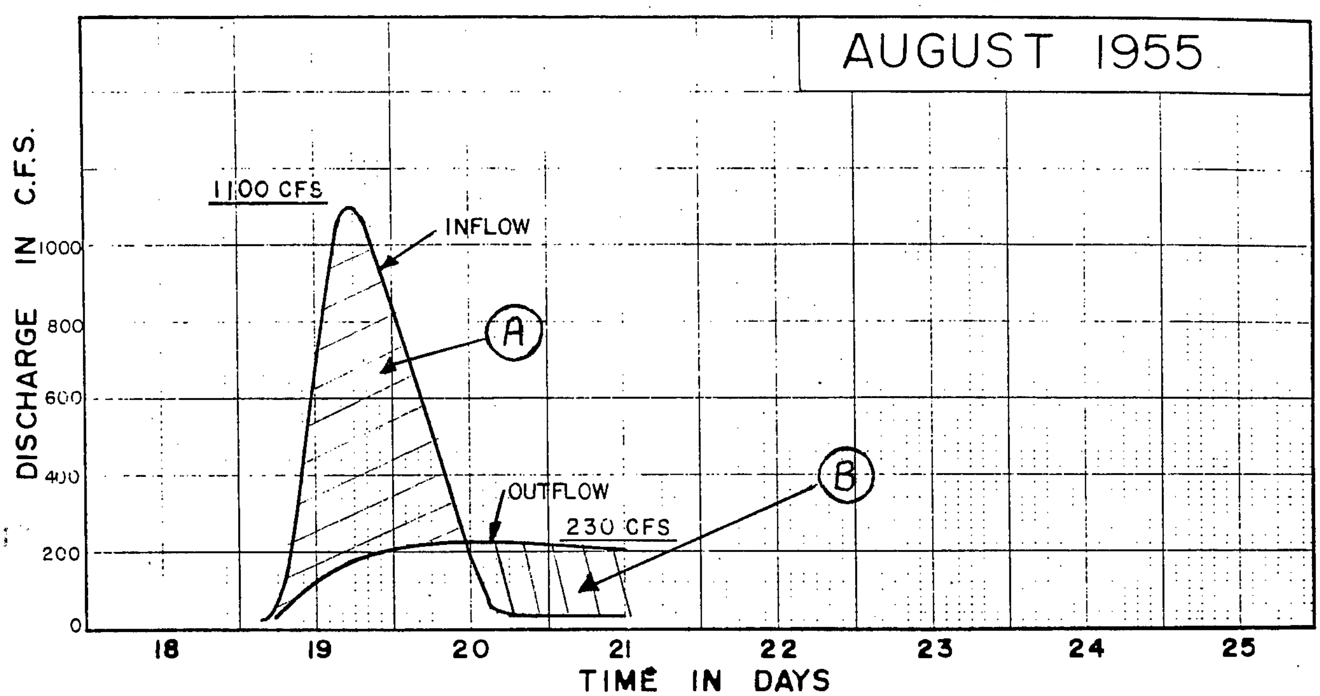



FIGURE C-5 Inflow and outflow from storage area "K" during the 1955 flood from the Charles River Study.

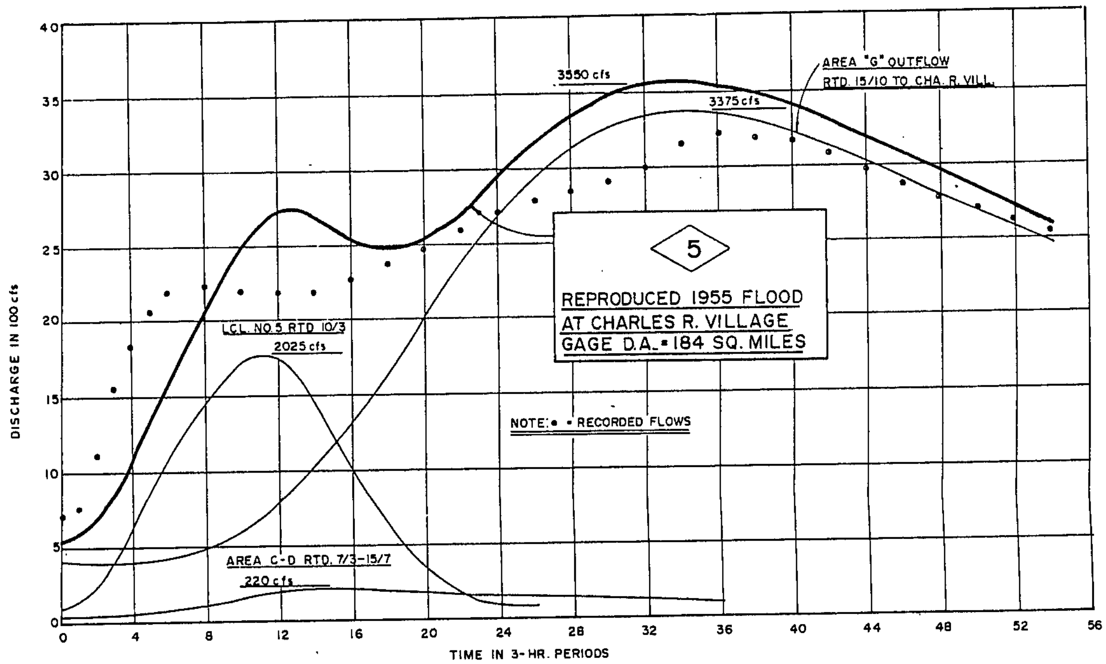



FIGURE C-6 Observed and computed hydrographs for the 1955 flood at the Charles River Village gage from the Charles River Study.

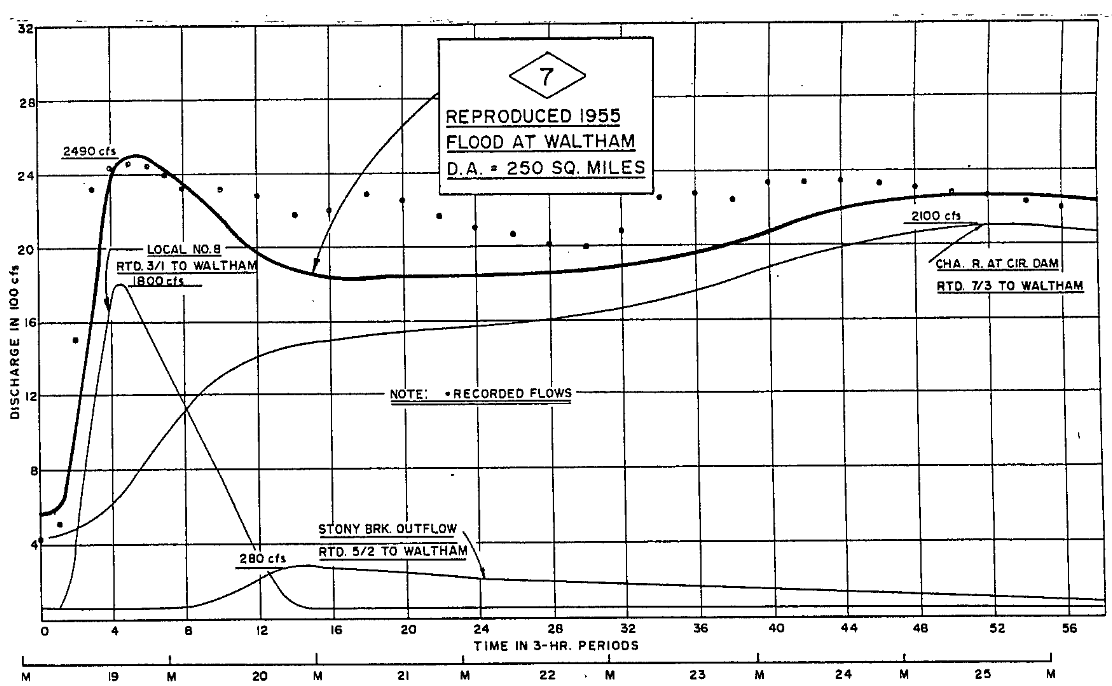



FIGURE C-7 Observed and computed hydrographs for the 1955 flood at the Waltham gage from the Charles River Study.

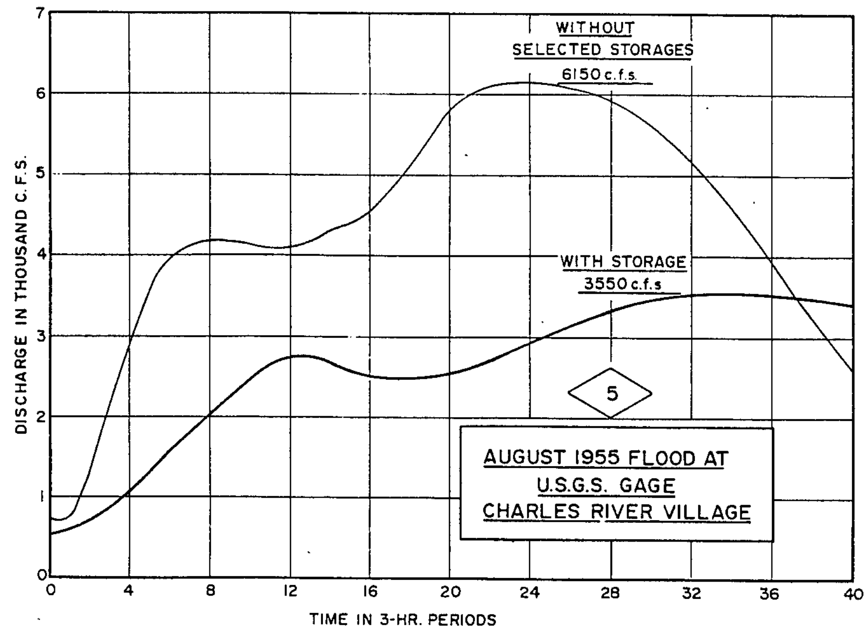



FIGURE C-8. Hydrographs at the Charles River Village gage representing the 1955 flood with and without selected storage areas from the Charles River Study.

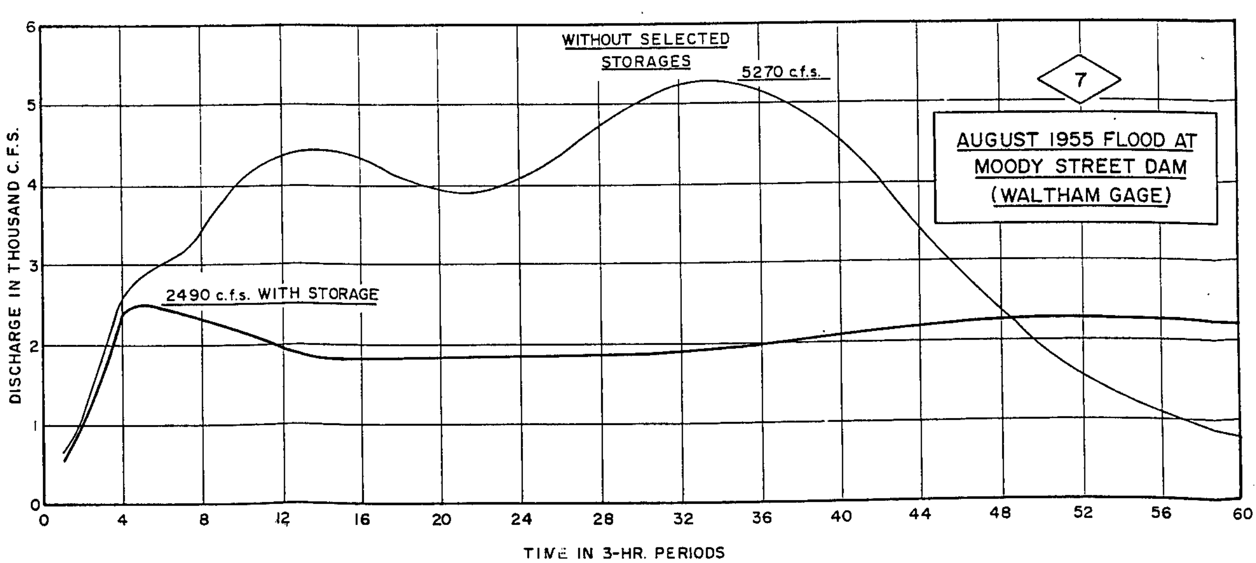
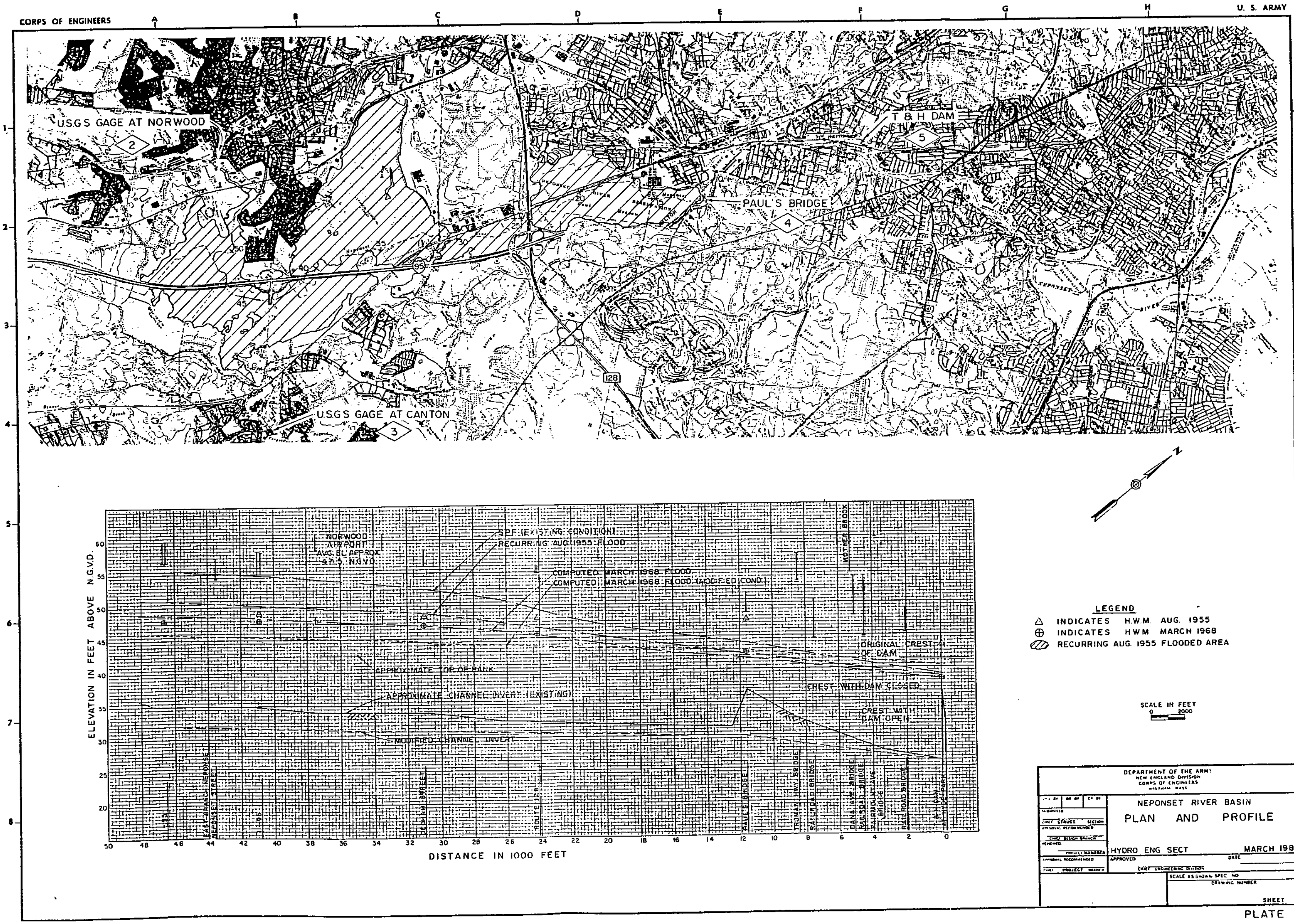
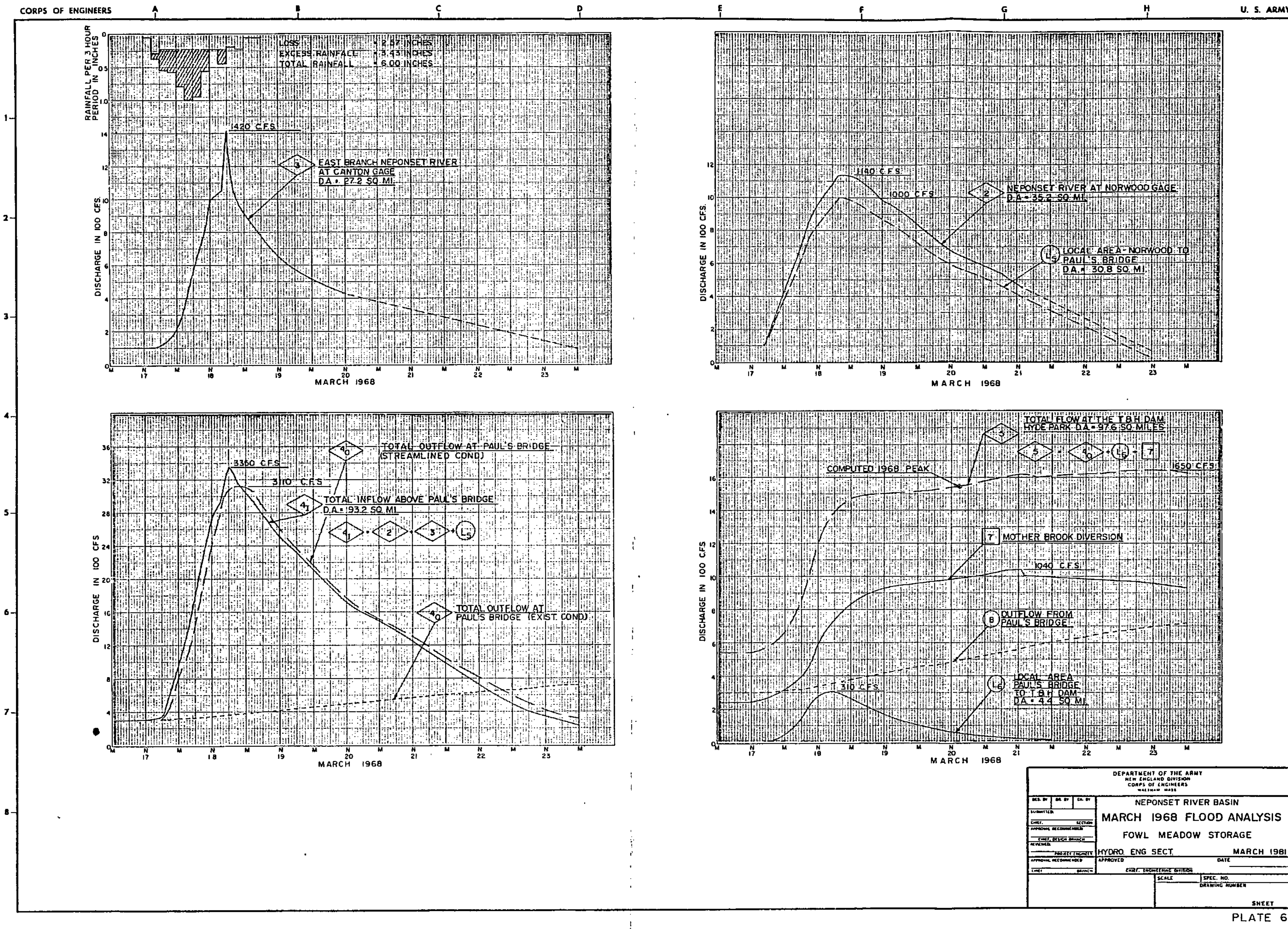



FIGURE C-9 Hydrographs at the Waltham gage representing the 1955 flood with and without selected storage areas from the Charles River Study.




River reach with off-channel storage and a sloping water surface profile from the Neponset River Study.

FIGURE C-10




Example inflow hydrographs developed for the Neponset River Study.

natural loss or possible encroachments on the flood plains. River profile results from the Neponset Study are shown in Figure C-10 as an example.

## 5. FLOOD CONTROL EFFECTIVENESS OF NATURAL VALLEY STORAGE

Storm runoff could increase due to disappearing watershed retention areas, decreasing the land's storage capacity, thereby threatening downstream areas with increased flood discharges. Filling of wetlands often leads to increased flood stages, resulting in greater flood damages upstream also.

The magnitude of a flood and the antecedent conditions within the watershed are factors in determining the storage effectiveness of natural valley storage areas. Natural valley storage has the greatest modifying effect on flash-type floods that peak and recede quickly, rather than long duration flooding when discharges remain high for a longer period. Change of storage in a floodplain only occurs as a result of change in stage, which in turn is a function of change of flow in the river. The relative magnitude of the effect of floodplain storage on outflow is therefore dependent on rate of rise of the flood crest, amount of floodplain area, and magnitude of riverflow. During rising flood stages, outflow from a reach is less than inflow by a flow amount equivalent to the rate of rise in stage; multiplied by the natural valley storage area. The amount the outflow peak is reduced below the inflow peak depends greatly on the type of flood. With a flash-type flood, reduction in peak discharge can approach the reduction between inflow and outflow experienced during the rising portion of the event. During long duration flooding, the effect of natural valley storage is minimal because outflow equals inflow once the areas are filled to the stage required to sustain peak flow.

The location of storage areas in relation to damage areas, and in comparison to the total drainage area, is also important to natural valley storage effectiveness in flood control. For example, storage with a small drainage area in the upper portion of a watershed, located on a first order stream, would have little impact on reducing peak flows if the main damage centers are located a considerable distance downstream with a much larger drainage area.

In the case of the Neponset River Study, the loss of its upstream storage areas had little effect on outflows from the large river reach storage area (Fowl Meadow). The effect of loss of upstream storage would be generally limited to tributary streams themselves, with the reason being the Fowl Meadow storage area is so large. The Upper Neponset and East Branch Rivers have approximately 1,200 acres of surface area and provide storage ranging from 3,000 to 5,000 acre-feet. In comparison, the downstream Fowl Meadow storage reach has a surface area of about 3,000 acres, providing approximately 15,000 to 30,000 acre-feet of storage.

## 6. IMPACTS OF LOSS OF NATURAL VALLEY STORAGE

It is difficult to generalize the effects of losing natural flood storage. Determining the effect filling storage areas has on flooding, requires complex hydraulic calculations. These include size of the watershed, total volume of unfilled floodplain, and percentage of

wetland storage in the system as well as a hydrologic determination of the total quantity of water which will be flowing through the watershed in a given flood. Some river systems experience major changes in flood depths and velocities when significant wetlands have been filled. However, some increases in flood elevations due to filling natural valley storage areas, can result in flooding additional land that would not have been inundated previously. Therefore, the downstream impact might not be as great as expected (Thomas, 1987).

As stated in the Charles River Watershed, Natural Valley Storage Project, Design Memorandum No. 1, dated May 1976:

> "In analyzing the effect of valley storage loss it is important to appreciate the significance of the term effective storage loss. When a quantity of valley storage is lost due to filling or diking there is also an increase in flood stages in adjacent areas. These increased stages create new flood storage in areas not previously inundated so that the net effective storage loss is normally something less than the original quantity of storage loss. However, the effect of creating increased flows and stages downstream, due to loss of upstream storage, often leads to pressures for remedial channel improvements, filling and diking which can have a compounding effect much greater than that originally computed for the initial incremental storage loss."

## 7. SUMMARY

Depending on the natural valley storage characteristics of the watershed being studied, both evaluation methods discussed can be used separately or combined, if necessary. The Neponset River Study, for example, was a combination of both.

If natural valley storage areas are lost, floodflows would increase stages into other nearby storage areas or flow downstream causing increased flood discharges. These effects could result in increased flood damages, both upstream and downstream.

Preserving the wetlands and floodplains that make up natural valley storage could be an effective flood control alternative for structural solutions and prevention of future flooding. Not preserving them could lead to necessary downstream structural solutions to counteract the effects of their loss.

## PART II
## NASHUA RIVER CASE STUDY

### 1. WATERSHED DESCRIPTION

a. General. The Nashua River Basin with a total watershed area of approximately 538 square miles includes all or part of 27 cities and towns in Massachusetts and eight in New Hampshire. The highest altitude is 2,006 feet NGVD at Wachusett Mountain and the elevation near the confluence with the Merrimack River in Nashua is about 121 feet NGVD. The watershed area consists of four major tributaries, the main stem of the river, generally rural landscapes, and numerous streams, lakes, and wetlands.

b. Nashua River. The main stem of the river originates at the confluence of the South Branch and North Nashua Rivers in Lancaster. The Nashua River is located on the east side of the watershed and flows in a generally northeast direction through the towns of Lancaster, Bolton, Harvard, Shirley, Ayer, Groton, Pepperell, and Dunstable, Massachusetts and Hollis and Nashua, New Hampshire until it enters the Merrimack River (see plate C-1). The main stem has a total fall of about 140 feet in a distance of approximately 41 miles for an average slope of about three feet per mile.

Like most streams in New England that drain in a northerly direction, the main stem of the Nashua is hydrologically a sluggish watershed with flat stream gradients and numerous wetlands and floodplains. The area with the majority of floodplains and natural storage is located between the confluence of the North Nashua River and East Pepperell, Massachusetts. The current study dealt mostly with this area due to the amount of natural valley storage within the river reach and its significance relative to the total Nashua River watershed.

c. North Nashua River. A major tributary to the Nashua River is the North Nashua which has a drainage area of 132 square miles at its confluence with the South Branch. The North Nashua River flows in a southeasterly direction and has an approximate length of 18 miles. The watershed contains numerous small lakes and ponds utilized for municipal water supply, limited hydroelectric power production, industrial water supply, and recreation purposes. Above Leominster, the topography is moderately steep and hilly, while the lower basin has milder slopes. The upper basin is largely forested and contains little tillable land. The slope averages 36 feet per mile through Fitchburg and 10 feet per mile from Fitchburg to the confluence with the South Branch. Most lakes in the North Nashua River Basin provide little flood reduction during major storms due to limited surcharge storage capacity and/or size of their respective drainage areas. This tributary produces relatively high run-off values and is a major contributor to floodflows.

d. South Branch Nashua River. At the USGS gage in Clinton, the drainage area of the South Branch is approximately 108 square miles. Most of this area is regulated by the Wachusett Reservoir just upstream. This

is a major water supply reservoir; therefore, the majority of the flow is diverted for the Massachusetts Water Resource Association's water supply system. However, during flood events, which fill the impoundment, releases from Wachusett Dam spillway are made.

e. Other Tributaries. There are two major tributaries other than the North Nashua River, namely, the Squannacook and Nississit Rivers, with drainage areas of approximately 71 and 60 square miles, respectively. The Squannacook drops about 100 feet in approximately 15 miles, and the Nississit approximately 90 feet in 10 miles.

## 2. CLIMATOLOGY

a. General. The Nashua River Basin has a variable climate, which frequently experiences periods of heavy precipitation produced by local thunderstorms and larger weather systems of tropical and extra-tropical origin. The basin lies in the path of prevailing "westerlies" which traverse the country in an easterly or northeasterly direction, producing frequent weather changes. Temperature extremes within the basin range from summertime highs of about 100 degrees ($^{O}$) Fahrenheit (F) to subzero temperatures in the minus teens occurring for short periods in the winter.

b. Temperature. The mean annual temperature in the Nashua River watershed is approximately 48 $^{O}$F. Recorded temperature extremes at Fitchburg vary from a maximum of 105 $^{O}$F to a minimum of -21 $^{O}$F. Freezing temperatures may be expected from late September to April. Table C-1 lists the mean, maximum, and minimum monthly and annual temperatures at Fitchburg for 89 years of record.

c. Precipitation. The average annual precipitation over the Nashua River Basin is approximately 46 inches, uniformly distributed throughout the year. The maximum annual precipitation at Clinton, Dunstable, and Fitchburg are 62.19, 58.32, and 58.09 inches, respectively. The minimum experienced annual precipitations are 27.97, 34.62, and 30.79 inches, respectively. Table C-2 lists the mean, maximum, and minimum monthly and annual precipitation at these three locations.

## 3. STREAMFLOW RECORDS

There are currently 5 streamflow gages maintained by the U.S. Geological Survey (USGS) in the Nashua watershed; North Nashua River at Fitchburg, North Nashua River at Leominster, South Branch Nashua River at Clinton, Squannacook River near West Groton, and Nashua River at East Pepperell. During this study, records from the latter four stations were utilized for flood analysis.

A continuous streamflow record has been maintained at Leominster since September 1935, constituting 56 years of record. Drainage area at the gage is 110 square miles. The long term average flow is 197 cubic feet per second (cfs), equivalent to 24.2 inches of annual runoff from the watershed. The maximum instantaneous discharge since 1850 was 16,300 cfs on 18 March 1936, while the minimum flow was 11 cfs on August 29, 1948.

TABLE C-1

MONTHLY TEMPERATURES

AT FITCHBURG, MASSACHUSETTS
(Degrees Fahrenheit)

| Month | Average | Maximum | Minimum |
|---|---|---|---|
| January | 24.8 | 68 | -21 |
| February | 25.0 | 68 | -21 |
| March | 34.5 | 86 | -8 |
| April | 46.0 | 92 | 6 |
| May | 57.7 | 97 | 26 |
| June | 66.4 | 100 | 35 |
| July | 71.6 | 103 | 40 |
| August | 69.3 | 105 | 35 |
| September | 62.1 | 101 | 27 |
| October | 51.3 | 91 | 16 |
| November | 39.9 | 81 | -2 |
| December | 28.6 | 71 | -16 |
| ANNUAL | 48.1 | | |

TABLE C-2

MONTHLY PRECIPITATION

| | Clinton, Massachusetts (1949-1985) | | | Dunstable, Massachusetts (1971-83, 85-86, 88-89) | | | Fitchburg, Massachusetts (1948-1978) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (in.) | Max (in.) | Min (in.) | Mean (in.) | Max (in.) | Min (in.) | Mean (in.) | Max (in.) | Min (in.) |
| January | 3.94 | 13.19 | 0.64 | 3.88 | 11.34 | 0.59 | 3.81 | 8.45 | 0.84 |
| February | 3.79 | 7.48 | 0.93 | 3.42 | 7.23 | 0.12 | 3.36 | 6.20 | 0.80 |
| March | 4.20 | 8.25 | 0.70 | 3.87 | 9.92 | 0.58 | 4.09 | 8.95 | 2.06 |
| April | 3.93 | 7.60 | 0.89 | 4.11 | 11.14 | 1.68 | 3.75 | 7.02 | 1.14 |
| May | 3.68 | 8.74 | 0.61 | 3.91 | 8.38 | 0.98 | 3.51 | 7.57 | 0.94 |
| June | 3.63 | 11.86 | 0.49 | 4.09 | 9.71 | 0.99 | 3.45 | 7.85 | 1.08 |
| July | 3.35 | 7.55 | 0.39 | 3.51 | 5.68 | 1.57 | 3.27 | 7.77 | 0.46 |
| August | 3.97 | 15.39 | 0.63 | 3.60 | 6.41 | 1.43 | 3.38 | 9.64 | 0.78 |
| September | 3.56 | 9.11 | 0.55 | 3.54 | 8.50 | 0.59 | 3.65 | 12.54 | 0.38 |
| October | 3.67 | 9.15 | 0.99 | 3.95 | 5.76 | 1.97 | 3.63 | 11.42 | 1.24 |
| November | 4.58 | 8.73 | 0.56 | 4.52 | 8.50 | 1.00 | 4.50 | 7.79 | 0.69 |
| December | 4.16 | 8.08 | 0.82 | 3.73 | 7.77 | 0.82 | 4.28 | 9.33 | 0.75 |
| ANNUAL | 46.49 | 62.19 | 27.97 | 46.03 | 58.32 | 34.62 | 43.96 | 58.09 | 30.79 |

The USGS gage on the South Branch Nashua River at Clinton currently only supplies basic monthly information; however, the Metropolitan District Commission (MDC) records show daily releases from the Wachusett Dam.

The Squannacook River gage has the shortest period of record, 42 years (1949-1991). Drainage area at the gage is 63.7 square miles. The average flow is 112 cfs, with a maximum discharge of 4,220 cfs on 6 April 1987 and a minimum daily discharge of 2.0 cfs on 7 September 1965.

The final USGS gage is in East Pepperell on the Nashua River just below the East Pepperell Dam, with drainage area of 435 square miles at the gage. The gage is located approximately 23.3 miles downstream from the confluence of the North Nashua River. This gage has a 56-year period of record since 1935. The long term average flow is 576 cfs or 17.9 inches of annual runoff from the entire watershed (Wachusett Reservoir has a significant effect on recorded average annual flow). The maximum instantaneous flow was 20,900 cfs on 20 March 1936, while the minimum daily flow was 1.1 cfs on 13 August 1939. Recorded peak annual discharges at the East Pepperell gage are shown in table C-3.

Table C-4 presents a summary of maximum, minimum, and mean monthly flows for the North Nashua at Leominster, Squannacook at West Groton, and Nashua at East Pepperell gages.

4. DESCRIPTION OF FLOODS

a. General. For the purposes of this study, three floods, based on their respective magnitude of peak discharges with consideration for the computed discharge-frequency relationship, were considered: March 1936, September 1938, and May/June 1984. The 1936 flood was the largest in the Nashua River basin to occur during the period of record. The 1938 event, the third largest, is estimated to be about a 20-year storm. Approaching the more frequent end of the frequency curve, the 1984 flood was also analyzed. Peak flows observed at the four gages for the three floods are shown in table C-5.

b. March 1936 Flood. The greatest flows at the Leominster and East Pepperell gages were 16,300 and 20,900 cfs, respectively, occurring as the result of a second storm in March 1936. Intermittent periods of moderate to heavy rainfall during the month, combined with considerable snowmelt, produced two distinct high flows. The first peak was largely the result of runoff from melting snow, with some contribution from moderate rainfall during the period 9-13 March. A second storm period of intense rainfall between the 16th and 19th produced the second peak.

c. September 1938 Flood. Rainfall associated with a hurricane that passed up the Connecticut River Valley produced high flows in the Nashua River Basin. In the North Nashua Basin, rainfall averaged about 7 inches on 18-21 September, with about 4 inches falling in a 24-hour period on the 20th. Peaks at the Leominster and East Pepperell gages were 10,300 and 10,200 cfs, respectively.

d. May/June 1984 Flood. During the last week of May, a large slow moving system passed through New England, bringing rainfall for approximately one week (May 28-June 3). The Nashua River Basin received 8 to 9 inches during that period, with 3.8 inches falling on May 29th. The peak discharges in Leominster and East Pepperell were 4,060 and 6,820 cfs, respectively.

5. PEAK DISCHARGE FREQUENCIES

A peak discharge-frequency curve was developed for the Nashua River at East Pepperell by a statistical analysis of annual peak flows using a Log Pearson Type III distribution. A total period of 55 years (1935-1990) was analyzed using the HECWRC computer program. The discharge-frequency curve has a mean of 3.59, a standard deviation of 0.21 and a computed skew of +0.78. A skew of +1.0 was adopted based on previous studies and the resulting curve is shown on plate C-7.

The discharge-frequency curve for the Nashua River in Nashua, New Hampshire, between two known damage areas near Mine Falls, was estimated using a drainage area ratio to the 0.7 exponential power. The drainage areas in East Pepperell, Massachusetts, and at Mine Falls, New Hampshire, are 435 and 525 square miles, respectively. The discharge-frequency curve at Mine Falls is also shown on plate C-7.

6. STUDY PROCEDURE

a. General. A review of the watershed, flood profiles, and available mapping as well as gage data led to recognizing that the Nashua River reach from confluence of the South Branch and North Nashua Rivers to East Pepperell has significant natural valley storage. The location and availability of flow records at gages (see plate C-1) also allow for a reasonable estimate of historic inflows and outflows from this reach. For these reasons, this river reach was selected for analysis.

Because this selected reach has a considerable length, storage capacity, hydraulic conveyance capability, and a sloping water surface elevation (similar to that discussed in Part I Section 4b.), it was decided to model it with an unsteady flow, dynamic routing program. The UNET computer program, "One Dimensional Unsteady Flow Through a Full Network of Open Channels" developed by Dr. Robert L. Barkau, (reference a) was used. UNET allows for spillways across the channel and lateral or uniform lateral flows into the river, among other things. This and its ability to produce initial backwater conditions along the reach made the UNET program an appropriate choice for the study.

b. Computer Model Development. The UNET computer model requires river and floodplain cross sectional data as well as information on any hydraulic controls along the river such as dams, bridges, etc. For study purposes, specific bridges were not included but two dams located within this reach of river were coded into the model as internal boundary conditions.

TABLE C-3

ANNUAL PEAK FLOWS

Nashua River at East Pepperell Gage
(D.A. = 435 Sq. Mi.)

| Water Year | Peak Discharge (cfs) | Water Year | Peak Discharge (cfs) |
|---|---|---|---|
| 1936 | 20900.00 | 1970 | 4560.00 |
| 1937 | 3530.00 | 1971 | 2970.00 |
| 1938 | 10200.00 | 1972 | 3840.00 |
| 1939 | 3040.00 | 1973 | 4050.00 |
| | | 1974 | 3650.00 |
| 1940 | 4020.00 | 1975 | 3290.00 |
| 1941 | 2260.00 | 1976 | 3760.00 |
| 1942 | 4710.00 | 1977 | 5640.00 |
| 1943 | 2340.00 | 1978 | 3920.00 |
| 1944 | 7100.00 | 1979 | 6110.00 |
| 1945 | 2600.00 | | |
| 1946 | 3440.00 | 1980 | 4120.00 |
| 1947 | 2360.00 | 1981 | 3940.00 |
| 1948 | 4110.00 | 1982 | 6660.00 |
| 1949 | 1950.00 | 1983 | 5570.00 |
| | | 1984 | 6820.00 |
| 1950 | 2360.00 | 1985 | 1990.00 |
| 1951 | 3410.00 | 1986 | 4520.00 |
| 1952 | 3590.00 | 1987 | 11700.00 |
| 1953 | 4170.00 | 1988 | 2530.00 |
| 1954 | 4860.00 | | |
| 1989 | 2540.00 | | |
| 1955 | 3270.00 | | |
| 1956 | 5880.00 | 1990 | 3260.00 |
| 1957 | 2080.00 | | |
| 1958 | 3520.00 | | |
| 1959 | 4000.00 | | |
| 1960 | 5640.00 | | |
| 1961 | 3140.00 | | |
| 1962 | 5020.00 | | |
| 1963 | 3800.00 | | |
| 1964 | 2390.00 | | |
| 1965 | 1380.00 | | |
| 1966 | 1520.00 | | |
| 1967 | 2960.00 | | |
| 1968 | 6900.00 | | |
| 1969 | 4350.00 | | |

TABLE C-4

MONTHLY RUNOFF
(cubic feet per second)

| | North Nashua River Leominster, MA. (D.A. = 110 sq. mi.) 56 years of record through 1991 | | | Squannacook River West Groton, MA. (D.A. = 63.7 sq. mi.) 42 years of record through 1991 | | | Nashua River East Pepperell, MA. (D.A. = 435 sq. mi.) 56 years of record through 1991 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| January | 205 | 465 | 50 | 117 | 323 | 20 | 588 | 1417 | 116 |
| February | 227 | 534 | 64 | 131 | 328 | 34 | 668 | 1544 | 186 |
| March | 377 | 1289 | 140 | 226 | 554 | 82 | 1137 | 3930 | 386 |
| April | 415 | 1126 | 133 | 277 | 654 | 76 | 1241 | 3676 | 369 |
| May | 245 | 503 | 85 | 149 | 343 | 52 | 729 | 1382 | 236 |
| June | 162 | 642 | 64 | 79 | 315 | 21 | 488 | 1976 | 154 |
| July | 91 | 392 | 43 | 37 | 85 | 8.3 | 257 | 1366 | 90 |
| August | 83 | 286 | 38 | 30 | 99 | 6.2 | 219 | 966 | 71 |
| September | 89 | 595 | 37 | 33 | 245 | 6.8 | 239 | 1671 | 84 |
| October | 111 | 606 | 39 | 52 | 296 | 9.4 | 301 | 1356 | 91 |
| November | 169 | 485 | 44 | 97 | 304 | 13 | 472 | 1781 | 108 |
| December | 198 | 520 | 59 | 117 | 301 | 23 | 580 | 1535 | 134 |
| ANNUAL | 197 | 307 | 81 | 112 | 174 | 36 | 576 | 969 | 214 |

TABLE C-5

PEAK FLOWS DURING THREE FLOOD EVENTS
(Peak Discharges in CFS)

| Date | North Nashua River Leominster (D.A.=110 sq mi) | South Branch Nashua River Clinton (D.A.=108 sq mi) | Squannacook River West Groton (D.A.=63.7 sq mi) | Nashua River East Pepperell (D.A.=435 sq mi) |
|---|---|---|---|---|
| March 1936 | 16,300 | 4,680 | N/A | 20,900 |
| September 1938 | 10,300 | 4,000* | N/A | 10,200 |
| May/June 1984 | 4,060 | 750* | 1,910 | 6,820 |

* Estimated, based on daily values
N/A = Not available

(1) <u>Cross Section Data</u>. Cross sections which represent almost 24 miles of the Nashua River from Lancaster to Pepperell were located from backup data files of Flood Insurance Studies of the appropriate towns. Approximately 2 to 3 cross sections per mile were chosen to represent the varied floodplain widths of the river's reach. A total of 72 cross sections were utilized.

(2) <u>Spillway Data</u>. There are two run-of-river dams within the study reach, one in Ayer about 11.35 miles from the confluence of the North Nashua River, and the other in Pepperell, just upstream of the gage at approximately river mile 23.2 (measured from the confluence of the North Nashua River). Weir lengths were scaled from FIS mapping, and weir coefficients were estimated so that the flood profiles at the dams as presented in the Flood Insurance Studies were approximated.

(3) <u>Flow Data</u>. For this study the floods of March 1936, September 1938, and May/June 1984 were analyzed. Hydrographs at Leominster, Clinton, and East Pepperell were obtained from data in USGS water supply papers detailing the 1936 and 1938 floods (references b and c, respectively). For the 1984 flood, USGS elevation-discharge relationships and gage heights for the Leominster, West Groton, and East Pepperell gages during the storm period were used to produce hydrographs. A 1984 hydrograph for Clinton was estimated from the MDC daily discharge records for Wachusett Dam.

Since the Squannacook gage was not installed until 1949, flow for this location was estimated based on Leominster gage data for the 1936 and 1938 floods. To obtain these estimates a relationship was determined based on the 1984 peak discharges at the Leominster and Squannacook gages. Contributions from the remaining local drainage area were based on the adopted Squannacook flow by drainage area ratio.

(4) <u>Upstream and Downstream Boundaries</u>. The combined inflow hydrograph from Leominster and Clinton was used as the upstream boundary, with a rating curve used for the downstream boundary. Since the East Pepperell gage was at the end of the study reach, the rating curve for the gage developed by the USGS was utilized. Extensions to the rating curve were determined based on peak discharges and high water marks at the gage for some historic floods.

(5) <u>Lateral Inflows</u>. Three estimated lateral inflows were determined: one for the Squannacook River (D.A.= 63.7 sq. mi.), another for local area 1 (D.A.= 58.3 sq. mi.) between the North Nashua and Catacoonamug Rivers and, a third for local area 2 (D.A.= 95 sq. mi.), representing remainder of the area between Catacoonamug River and the East Pepperell gage (see plate C-1).

Inflow from the Squannacook River was initially based on a peak discharge ratio with Leominster gage flow data, while inflow from the two local areas, was based on a drainage area ratio between their drainage area and that of the Squannacook gage. The estimated hydrographs for the Squannacook gage and two local areas were used as uniform (for stability purposes) lateral inputs to the computer model.

c. Analysis

(1) Existing Conditions. There are three steps in calibrating the model for this study. First, the initial steady state backwater elevations, based on a discharge of 2,500 cfs, were compared to the Flood Insurance Study profiles. Knowing the discharges used to compute the various profiles in the FIS, the initial condition backwater of UNET was calibrated. Second, the 1936 flood simulation was calibrated to approximately reproduce the surveyed high water marks along the study reach. Last, was to reproduce the observed hydrograph for the given flood at the East Pepperell gage.

The observed high watermark data for the 1936 and 1938 floods, as well as the peak elevation results from the computer model for the 1936 flood, are shown on the river profiles on plates C-5 and C-6. There was no high water mark data for the 1984 flood along the Nashua River.

Reproducing the hydrograph at the East Pepperell gage required some adjustment to initially estimate lateral inflows in order to approximate the volume of runoff under the observed hydrograph. The lateral inflows were decreased by a percentage, based on the differences between the volume recorded at East Pepperell versus the volume recorded at Leominster and Clinton. For the 1936 flood, decreases to initial estimates of the two local areas were 50 percent. The adopted lateral inflow hydrographs for 1936 are shown on plate C-2. As shown on plate C-2, which presents the 1936 flood analysis, exact calibration of the discharge hydrograph at the East Pepperell gage was not obtained. The computed hydrograph peaked about 12 hours earlier than the observed hydrograph, and about 7 percent lower in discharge. Many sensitivity analyses were conducted by adjusting various parameters within UNET such as manning's "n" coefficients, lagging local inflows, interpolating cross sections, etc. The analysis, as presented in plate C-2, was determined the most representative and reproduced the observed high water marks very well as shown on plates C-5 and C-6.

Once the 1936 flood was calibrated, the adopted model was used for the 1938 and 1984 events. Computed hydrographs are shown on plates C-3 and C-4 for the 1938 and 1984 floods, respectively. As can be observed, the 1938 flood also peaked earlier and higher than the observed, while the 1984 flood peaked somewhat later; however, with approximately the same peak discharge as the observed. The accuracy of reproducing these three flood events is considered adequate for purposes of the study.

(2) Assumed Storage Loss. Since the 1936 flood event is the flood of record for the Nashua River Basin, it was used to represent an upper limit in establishing NVS extent and as the basis for estimating storage loss. From the UNET computer model run for the 1936 flood, the peak elevation and top width (length of water surface across the flood plain) for each cross section were determined. Losses of 10, 30, and 50 percent were considered. The losses were represented by taking the appropriate percent of the 1936 top width for each cross section along the river reach to estimate approximately 10, 30, and 50 percent loss of the area. Approximately 4,800 acres were flooded during March 1936 at an average

depth of approximately 7 feet. This storage represented about 33,600 acre-feet or 1.5 inches of runoff for the 435square mile watershed. The areas after 10, 30, and 50 percent losses are approximately 4,300, 3,400, and 2,400 acres, respectively.

Computer runs were made for each storm with 10, 30, and 50 percent loss of storage (based on the 1936 flooded area). The resulting impacts the loss of storage had on the downstream hydrograph at East Pepperell for each flood is shown on plates C-2, C-3, and C-4.

d. Results. Since calibration of the discharge hydrographs was not exact, the percent increase in the three computed hydrographs for various percent losses of storage was determined. This percent increase was then applied to the recorded discharge for each flood event and revised discharge-frequencies were determined, addressing the effects of storage loss. Discharge-frequency curves at the East Pepperell gage that represent existing, 10, 30, and 50 percent losses are shown on plate C-8. These curves were increased by a drainage area relationship to determine the revised discharge-frequencies at damage centers in Nashua, NH (plate C-9).

Two different damage areas with distinctly varied stage-discharge curves were identified in Nashua. One is located upstream of Mine Falls Dam, and the other upstream of Jackson Mills Dam. Two different stage-frequency curves illustrating the results upstream storage losses would have on each location were developed.

The existing stage-discharge curves were developed from flood profiles presented in the Nashua Flood Insurance Study near the two damage areas. These stage-discharge curves and the adopted discharge-frequency curve for Mine Falls (between the two damage areas) were used to develop existing condition stage-frequencies. Stage-frequency curves illustrating the storage losses were developed in a similar manner from the various percent loss discharge-frequency curves and are shown on plates C-10 and C-11.

## 7. CONCLUSION

This case study has demonstrated the effects of losing 10 an 30 percent of the record floodplain area and its general results for three different floods. The losses had the most impact on the record 1936 flood due to the larger amount of previously inundated area being lost. On the other hand, the 1984 flood, which is a more frequently occurring event, showed less increase because of the smaller area inundated during that event.

Stages downstream due to various losses of storage increased significantly. For a 100-year flood event, elevations downstream above, Mine Falls and Jackson Mills Dams, increased by 0.6 and 0.7 feet for the 10 percent loss of storage, respectively, and by 1.2 and 1.7 feet for the 30 percent loss, respectively. These increases in stages are a result of increased flood discharge due to the loss of upstream NVS. When analyzing the NVS area for the 30 percent loss scenario some encroachment into the FEMA designated floodway was assumed. This analysis resulted in flood stage increases of over 1 foot throughout much of the NVS area. These

increases are due to the effects of reduced flow area and storage volume along with the resulting increases to flood discharge calculated by the one-dimensional unsteady flow model used in this study.

Based on 1936 flood analysis of the study reach from Lancaster to East Pepperell, the increase in discharge per acre-foot of storage loss from the study reach is about 0.2 cfs/acre-foot. If more detailed information is desired concerning storage in lakes, smaller areas, and upper parts of the watershed, it would require HEC-1 analysis (as discussed in Part I, Section 4a.) to establish the value of their storage. This amount of detail was beyond the scope of this study. Another resource for a more detailed study would be orthophotoquad maps, which present more detailed information about topography and types of land than regular quad sheets.

8. REFERENCES

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b. U.S. Department of the Interior, Geological Survey Water Supply Paper 798, "The Floods of March 1936, Part 1, New England Rivers," 1937.

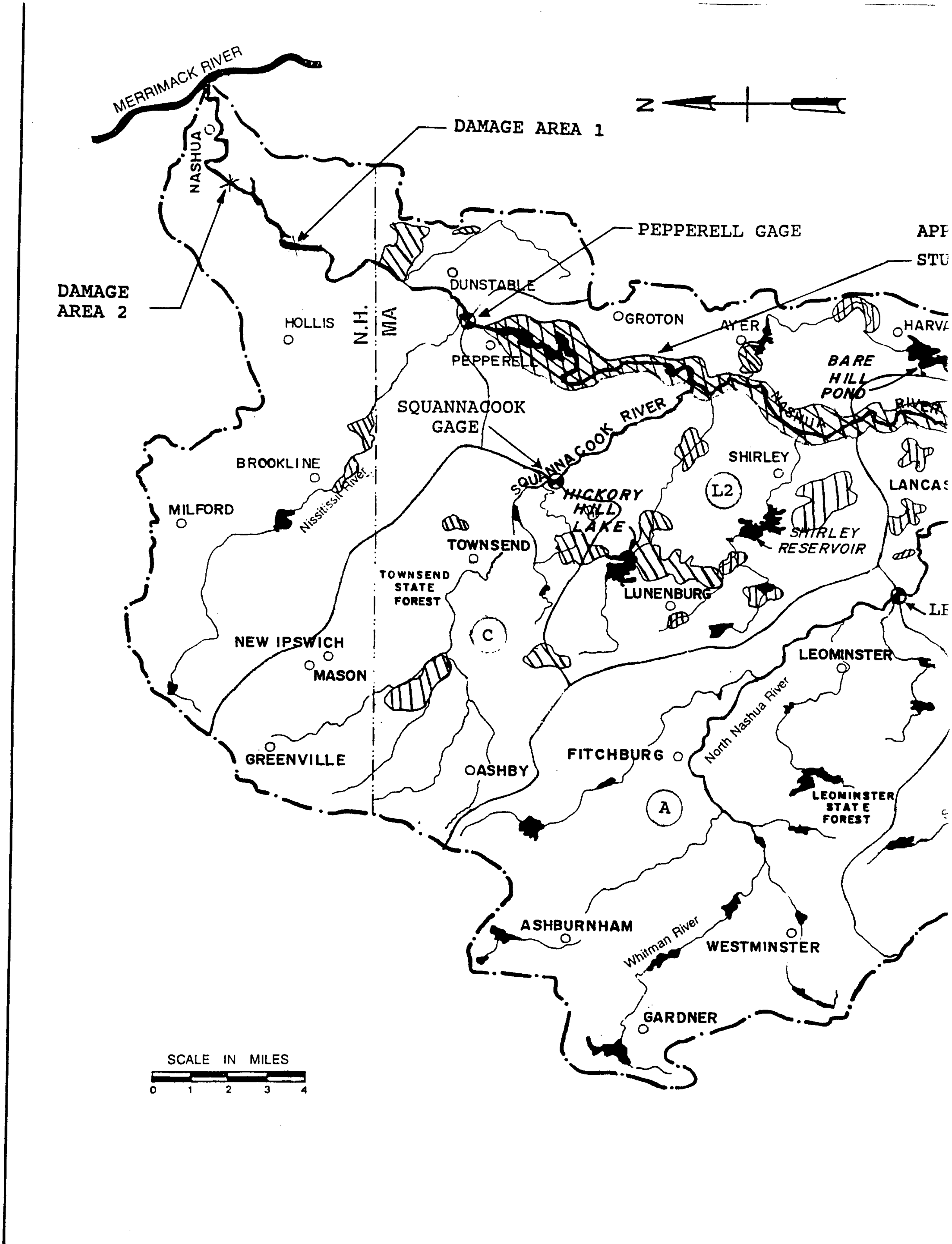
c. U.S. Department of the Interior, Geological Survey Water Supply Paper 867, "Hurricane Floods of September 1938," 1940.

d. Federal Emergency Management Agency, Federal Insurance Administration, "Flood Insurance Studies--Bolton, Lancaster, Shirley, Ayer, Harvard, Groton, Pepperell, Dunstable, MA, and Nashua, NH," mapping, profile books and back-up HEC-2 files, various dates (1978-1983).

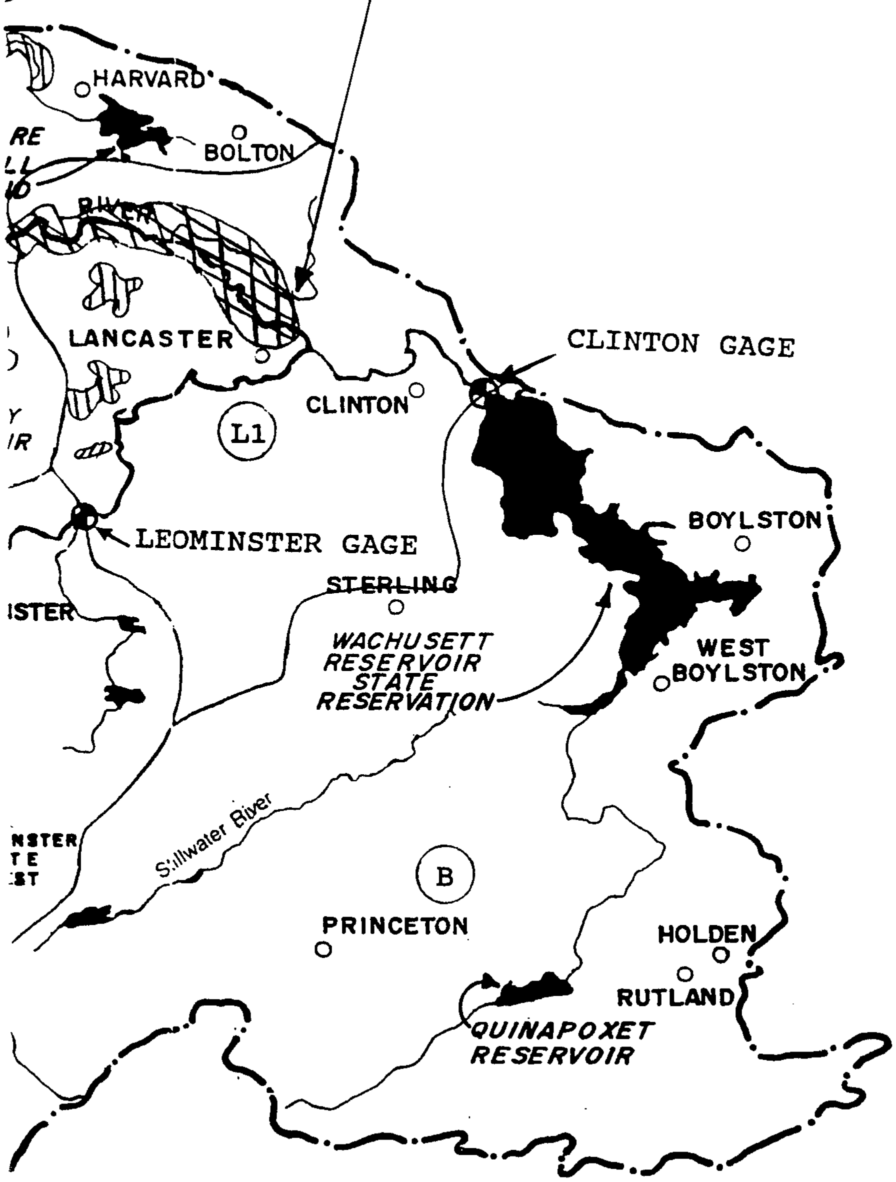
e. Nashua River Watershed Association, "Plan for the Nashua River Watershed," Roy Mann Associates, October 1972.

f. U.S. Army Corps of Engineers, New England Division, "North Nashua River Basin, Fitchburg, MA, Design Memorandum No. 1," December 1977.

g. U.S. Army Corps of Engineers, New England Division, Reservoir Control Center, "1984 Annual Report," 1985.


MERRIMACK RIVER
NASHUA
DAMAGE AREA 1
DAMAGE AREA 2
PEPPERELL GAGE
APP
STU
DUNSTABLE
HOLLIS
N.H.
MA
GROTON
AYER
HARVA
PEPPERELL
BARE HILL POND
NASHUA
RIVER
SQUANNACOOK GAGE
SQUANNACOOK RIVER
BROOKLINE
Nissitissit River
MILFORD
SHIRLEY
L2
HICKORY HILL LAKE
SHIRLEY RESERVOIR
LANCAS
TOWNSEND
TOWNSEND STATE FOREST
LUNENBURG
C
NEW IPSWICH
MASON
LEOMINSTER
GREENVILLE
ASHBY
FITCHBURG
North Nashua River
A
LEOMINSTER STATE FOREST
ASHBURNHAM
Whitman River
WESTMINSTER
GARDNER
SCALE IN MILES
0 1 2 3 4

| | | | |
|---|---|---|---|
| (A) | LEOMINSTER GAGE | D.A. = 110 sq. | |
| (B) | CLINTON GAGE | D.A. = 108 sq.. | |
| (C) | SQUANNACOOK GAGE | D.A. = 63.7 sq | |
| (L1) | LATERAL INFLOW #1 | D.A. = 58.3 sq | |
| (L2) | LATERAL INFLOW #2 | D.A. = 95 sq.m | |
| TOTAL D.A. AT PEPPERELL GAGE = 435 sq.: | | | |




LEGEND

APPROXIMATE D.A. BOUND/

U.S.G.S. GAGE

LARGER STORAGE AREAS

STORAGE REACH FOR STUDY

X APPROXIMATE DAMAGE AREA

NASHUA RIVER WAT

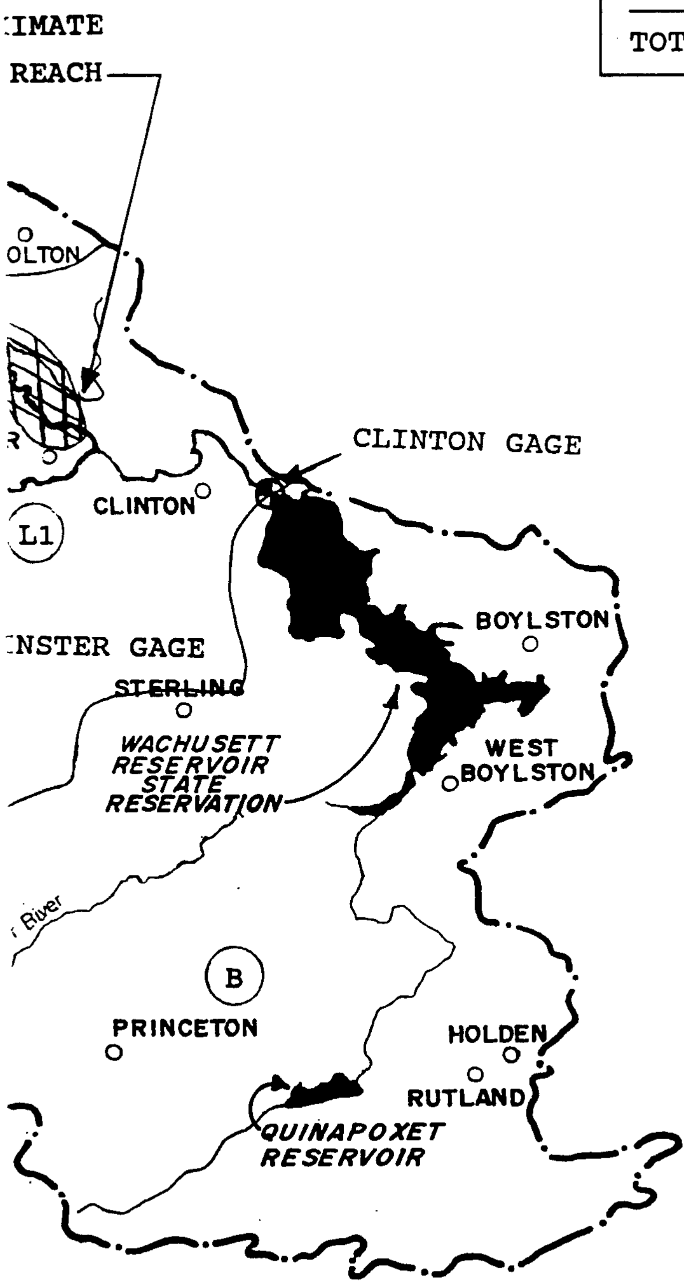
BASIN MAP

PLATE C-1

HEB AUGU:

2

| | | | |
|---|---|---|---|
| (A) | LEOMINSTER GAGE | D.A. = | 110 sq.mi. |
| (B) | CLINTON GAGE | D.A. = | 108 sq.mi. |
| (C) | SQUANNACOOK GAGE | D.A. = | 63.7 sq.mi. |
| (L1) | LATERAL INFLOW #1 | D.A. = | 58.3 sq.mi. |
| (L2) | LATERAL INFLOW #2 | D.A. = | 95 sq.mi. |
| TOTAL D.A. AT PEPPERELL GAGE | | = | 435 sq.mi. |




LEGEND

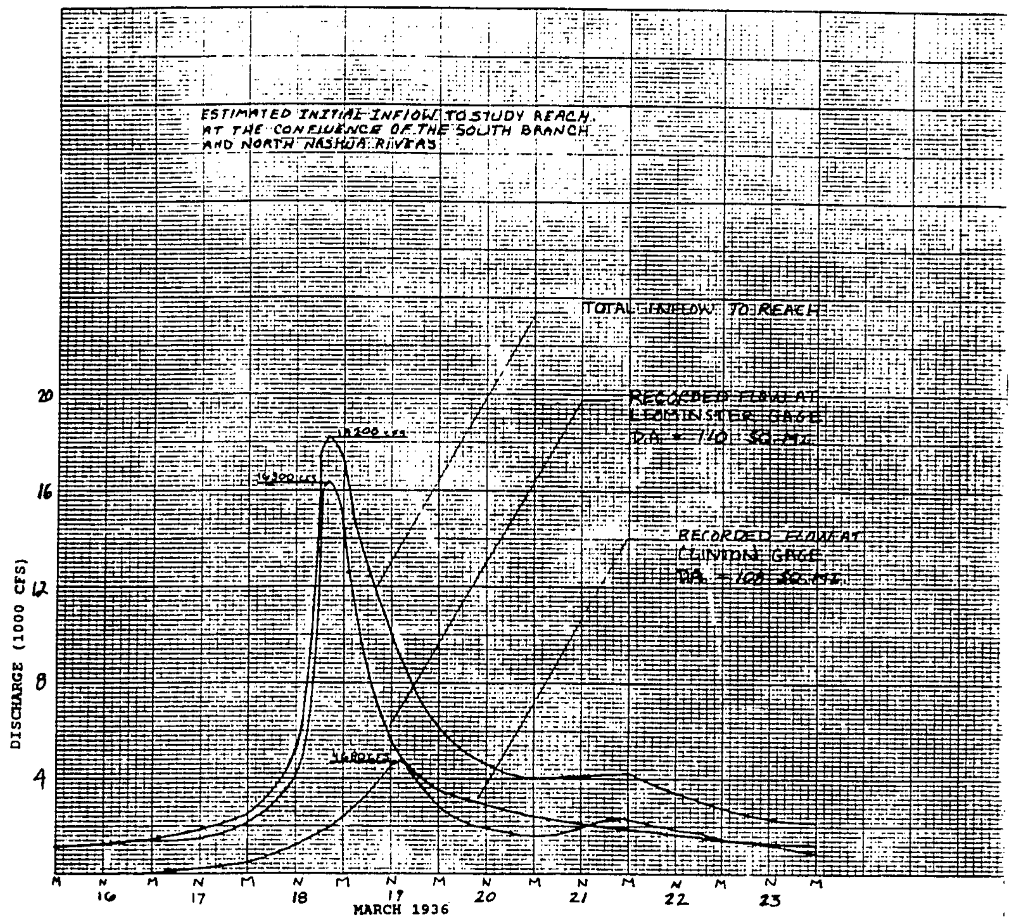
- APPROXIMATE D.A. BOUNDARIES
- U.S.G.S. GAGE
- LARGER STORAGE AREAS
- STORAGE REACH FOR STUDY
- X APPROXIMATE DAMAGE AREAS

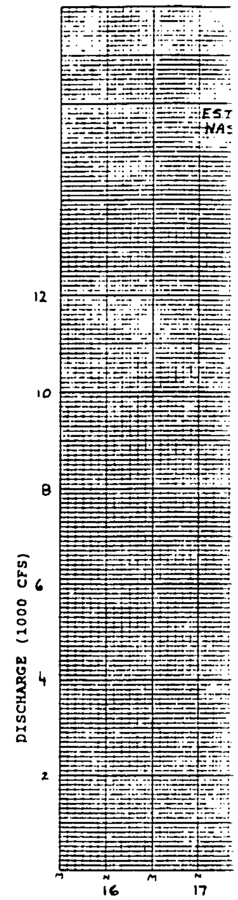
NASHUA RIVER WATERSHED

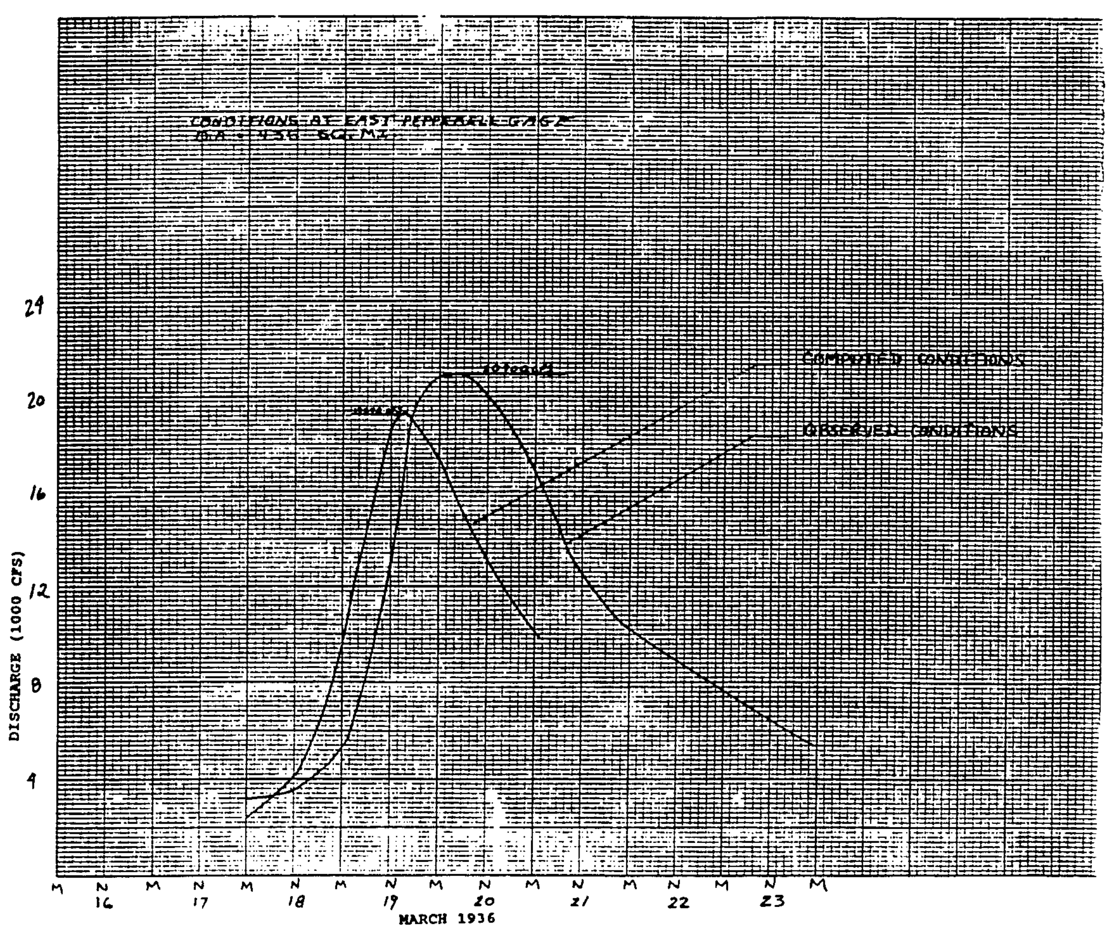
BASIN MAP

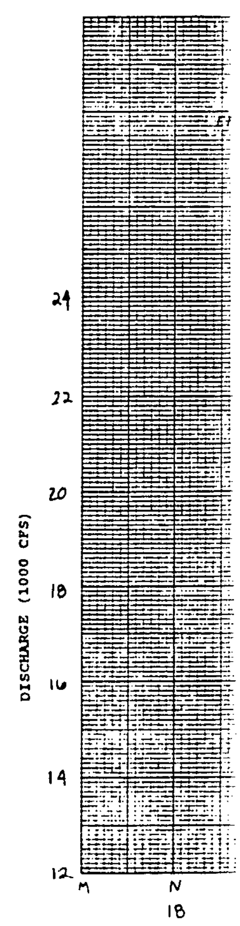
PLATE C-1

HEB AUGUST 1992

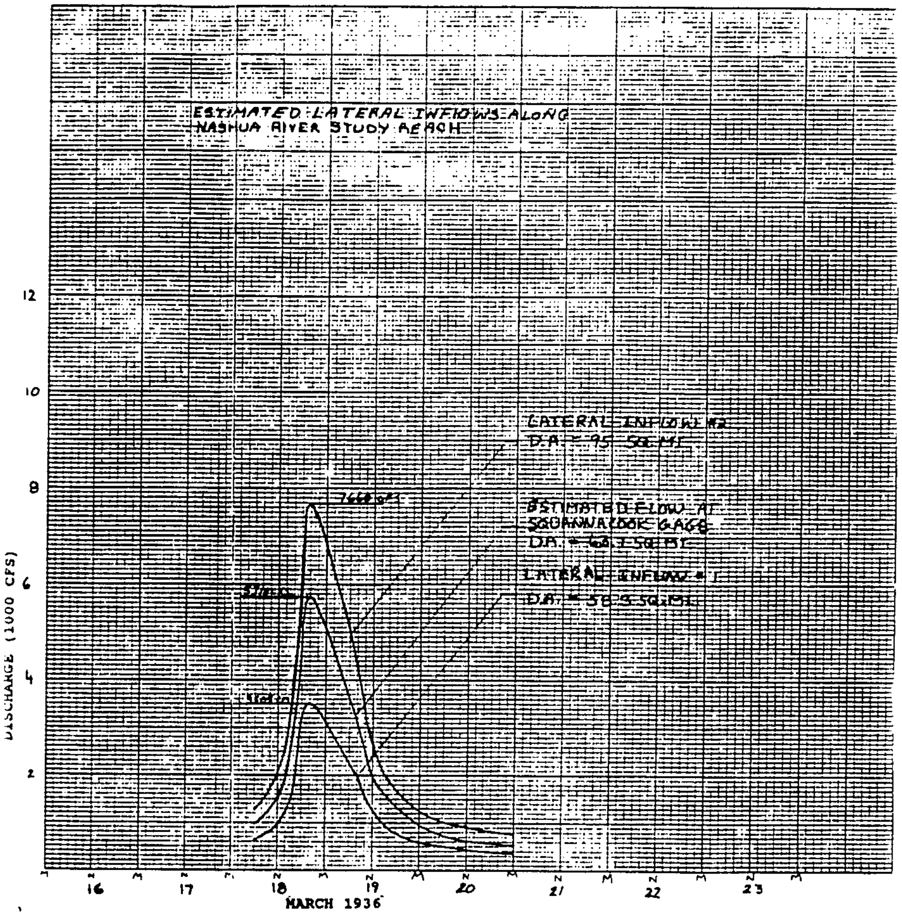

ESTIMATED INITIAL INFLOW TO STUDY REACH AT THE CONFLUENCE OF THE SOUTH BRANCH AND NORTH NASHUA RIVERS
TOTAL INFLOW TO REACH
RECORDED FLOW AT LEOMINSTER GAGE D.A. = 110 SQ. MI.
RECORDED FLOW AT CLINTON GAGE D.A. = 108 SQ. MI.
18200 cfs
16300 cfs
DISCHARGE (1000 CFS)
MARCH 1936

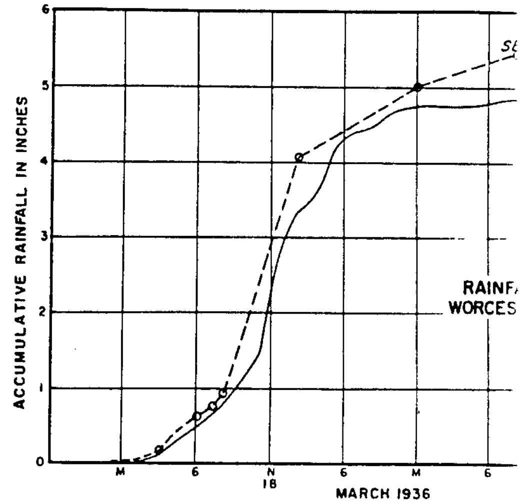

DISCHARGE (1000 CFS)

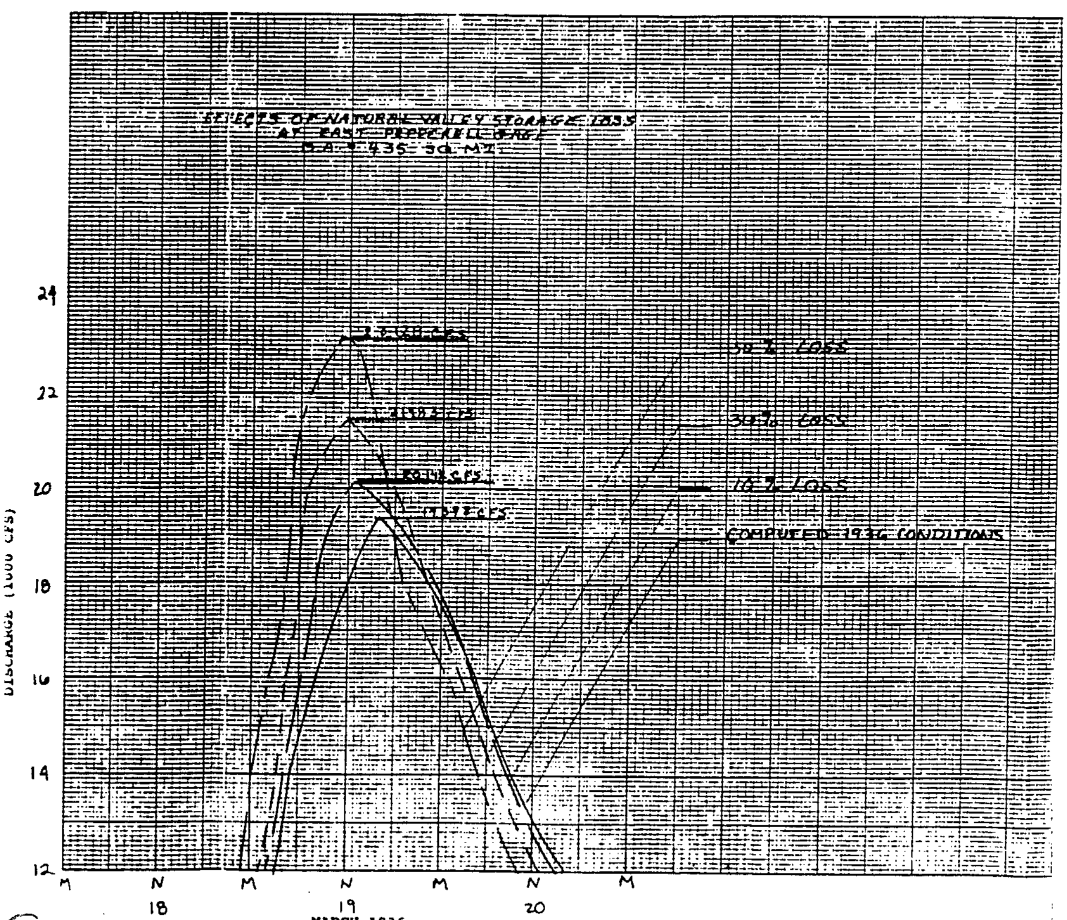

CONDITIONS AT EAST PEPPERELL GAGE D.A. = 436 SQ. MI.
COMPUTED CONDITIONS
OBSERVED CONDITIONS
DISCHARGE (1000 CFS)
MARCH 1936


DISCHARGE (1000 CFS)

(1)



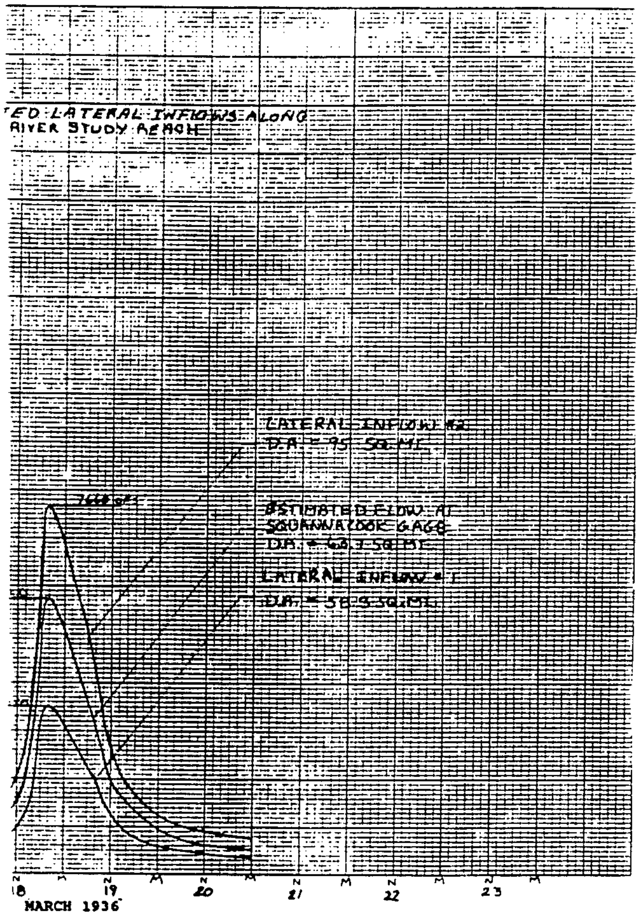

NASHUA RIVER BAS

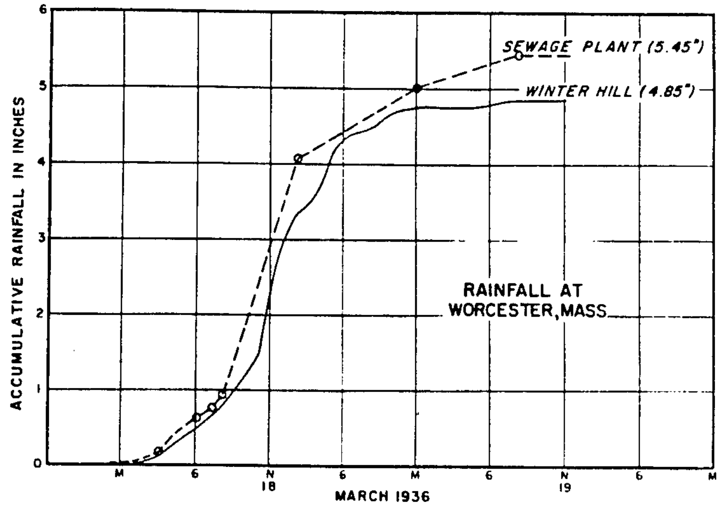
MARCH 1936 FLOOD ANA

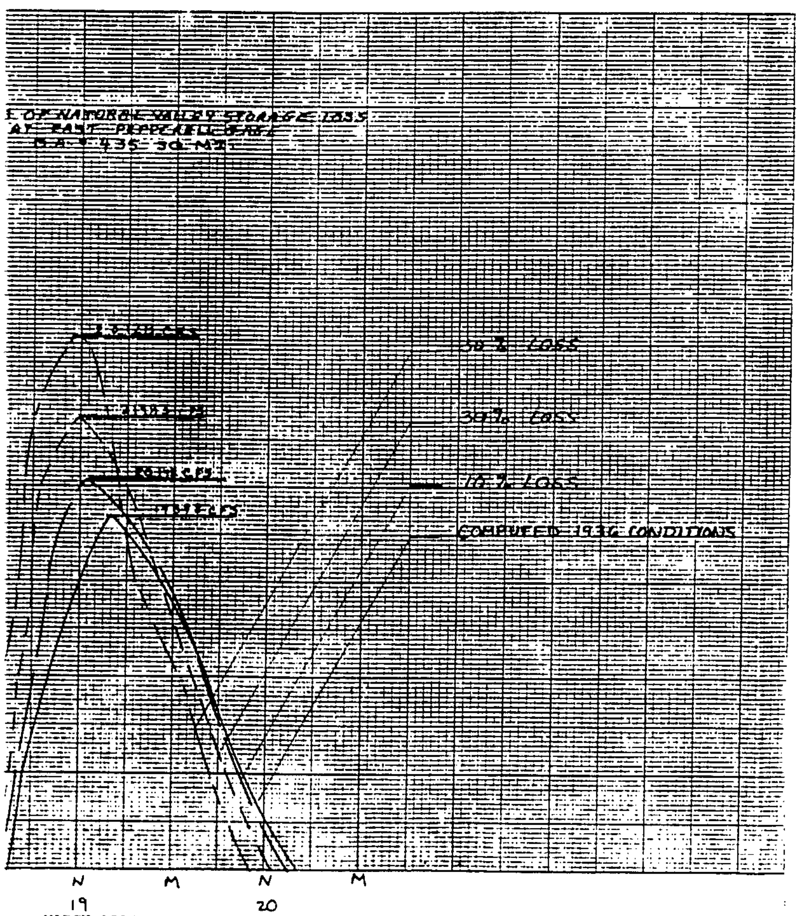
Lancaster to Pepperel

H.E.B. Au

(2)




NASHUA RIVER BASIN

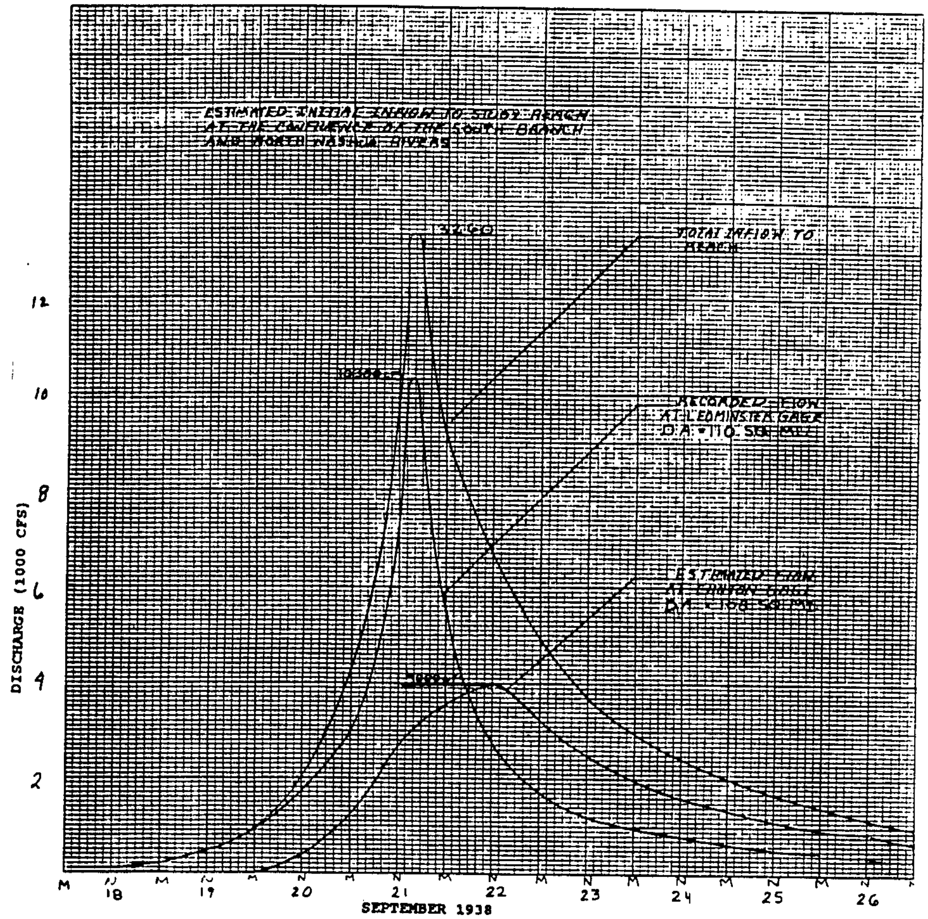
MARCH 1936 FLOOD ANALYSIS

Lancaster to Pepperell Reach

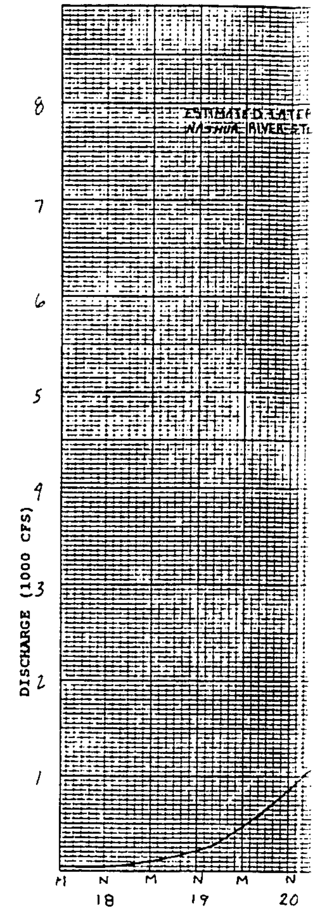
H.E.B. August 1992

PLATE C-2

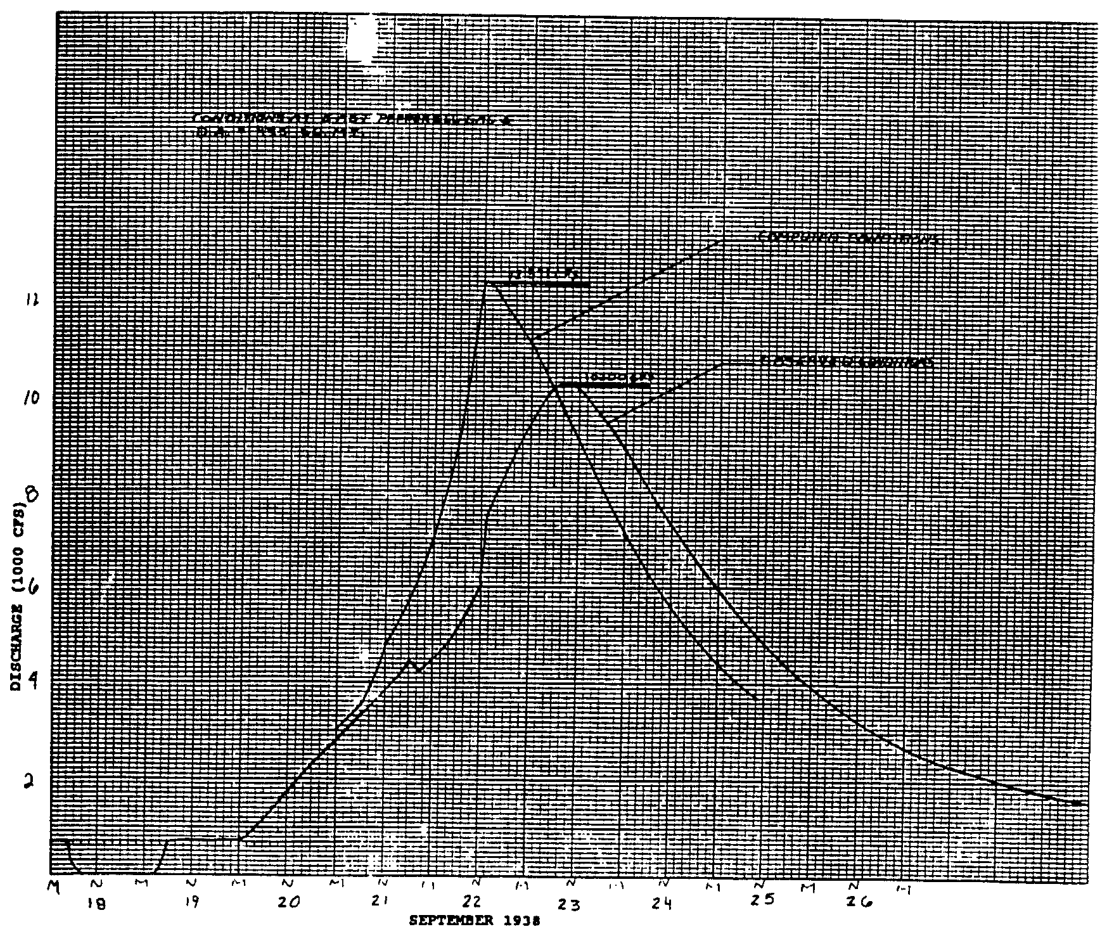
(3)



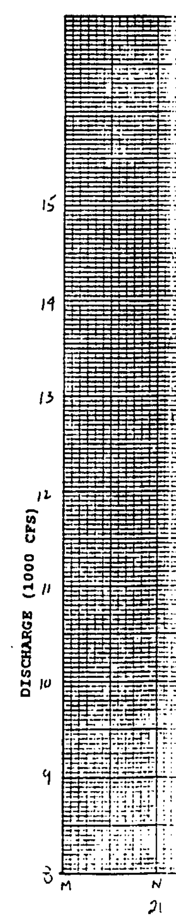
ESTIMATED INITIAL INFLOW TO STUDY REACH AT THE CONFLUENCE OF THE SOUTH BRANCH AND NORTH NASHUA RIVERS
TOTAL INFLOW TO REACH
RECORDED FLOW AT LEOMINSTER GAGE D.A.=110. SQ MI.
DISCHARGE (1000 CFS)
2
4
6
8
10
12
M N M N M N M N M N M N M N M N M N
18 19 20 21 22 23 24 25 26
SEPTEMBER 1938

DISCHARGE (1000 CFS)
1
2
3
4
5
6
7
8
M N M N M
18 19 20

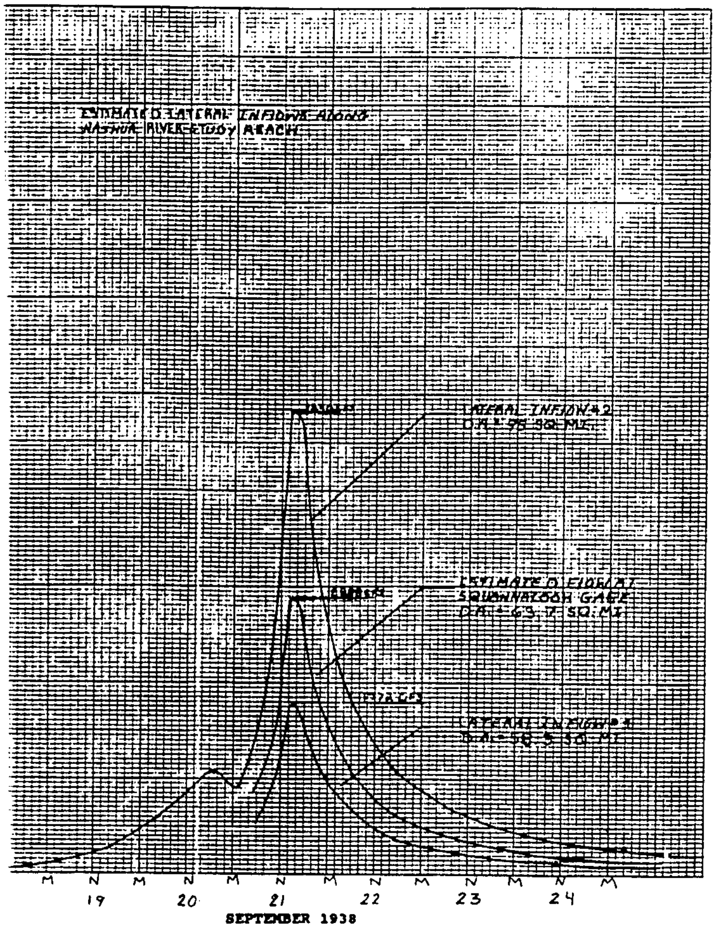



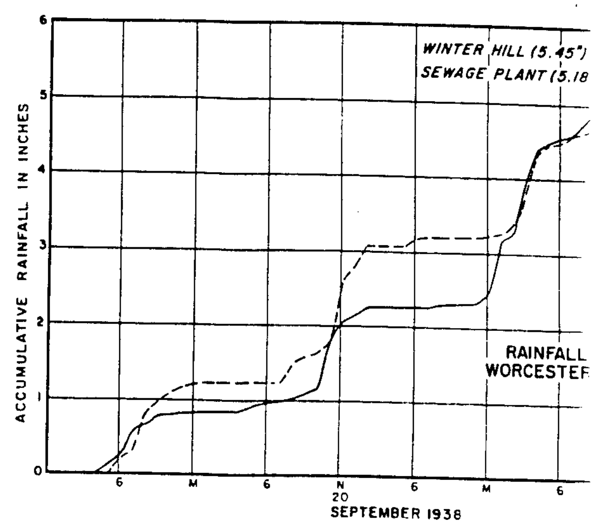
DISCHARGE (1000 CFS)
2
4
6
8
10
12
M N M N M N M N M N M N M N M N M N M
18 19 20 21 22 23 24 25 26
SEPTEMBER 1938

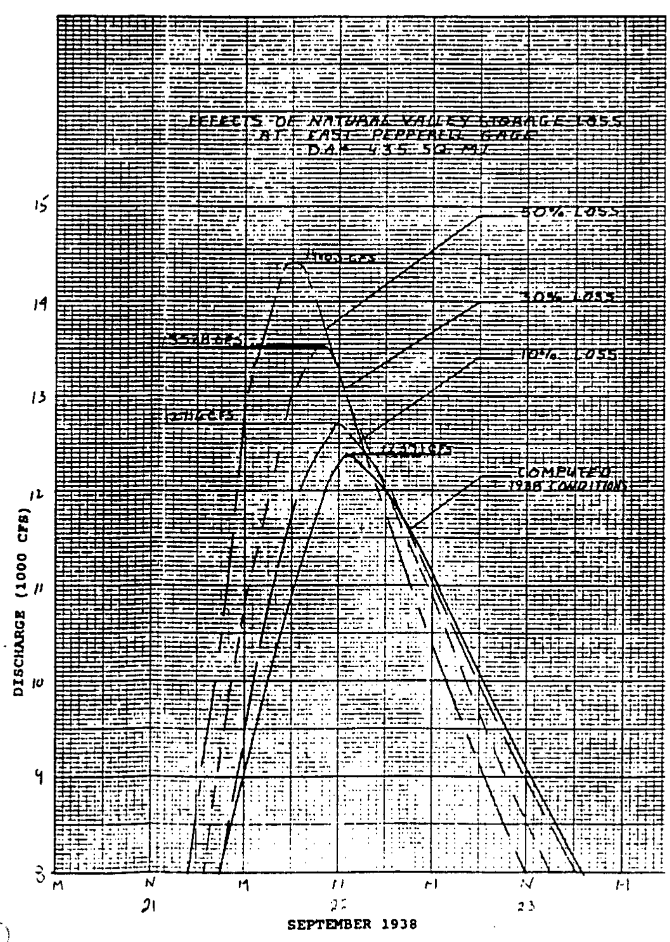



DISCHARGE (1000 CFS)
8
9
10
11
12
13
14
15
M N
21


1




NASHUA RIVER BASIN

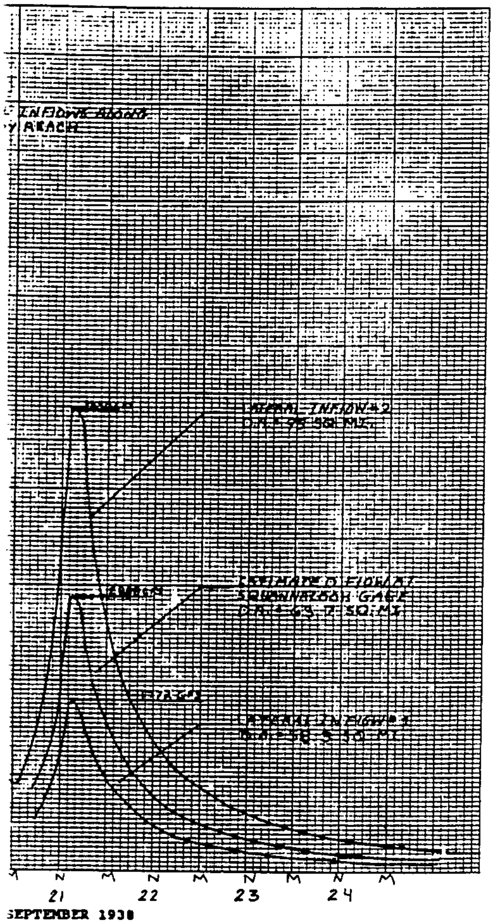
SEPTEMBER 1938 FLOOD ANAL

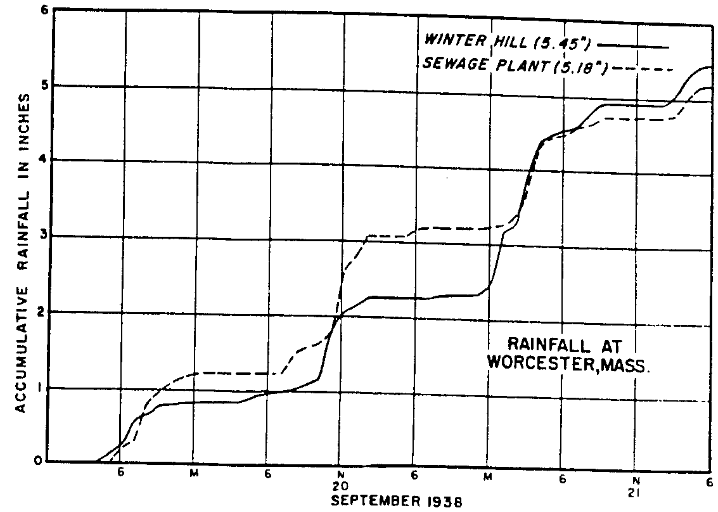
Lancaster to Pepperell Re

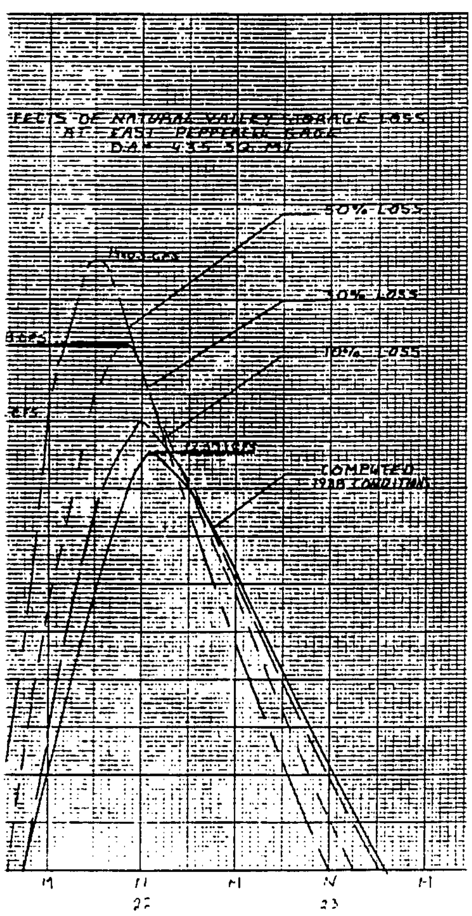
H.E.B. August

PLATE

(2)



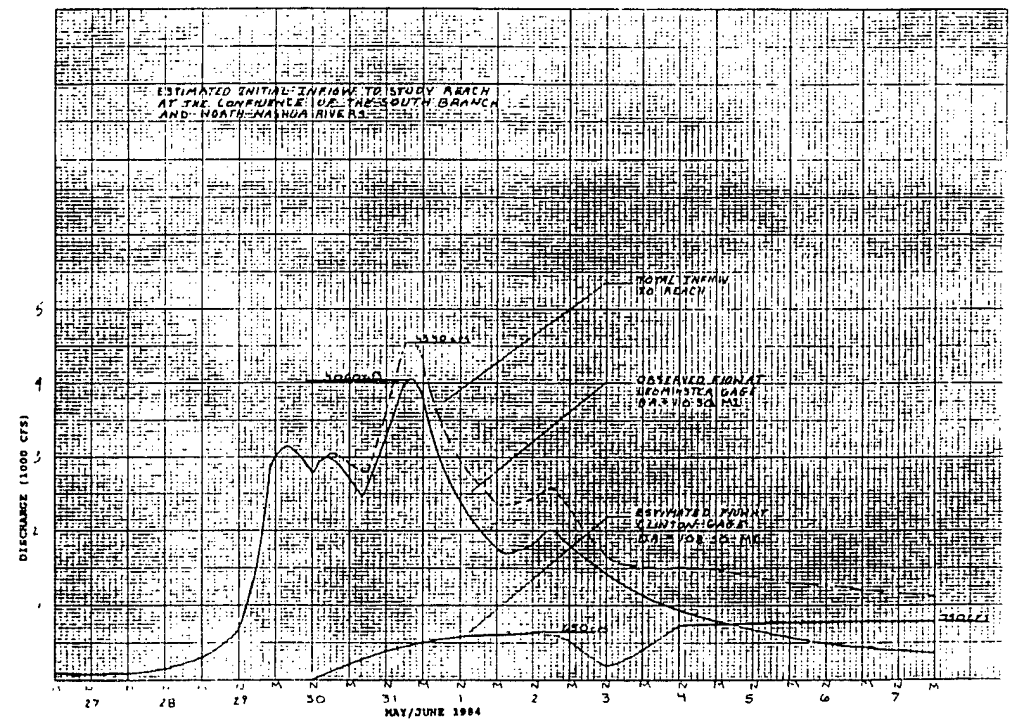

NASHUA RIVER BASIN

SEPTEMBER 1938 FLOOD ANALYSIS

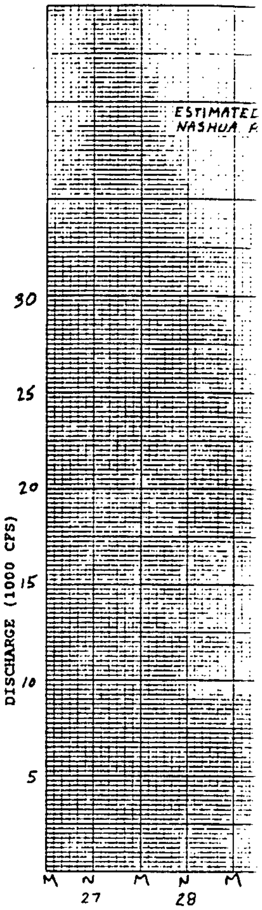
Lancaster to Pepperell Reach

H.E.B. August 1992

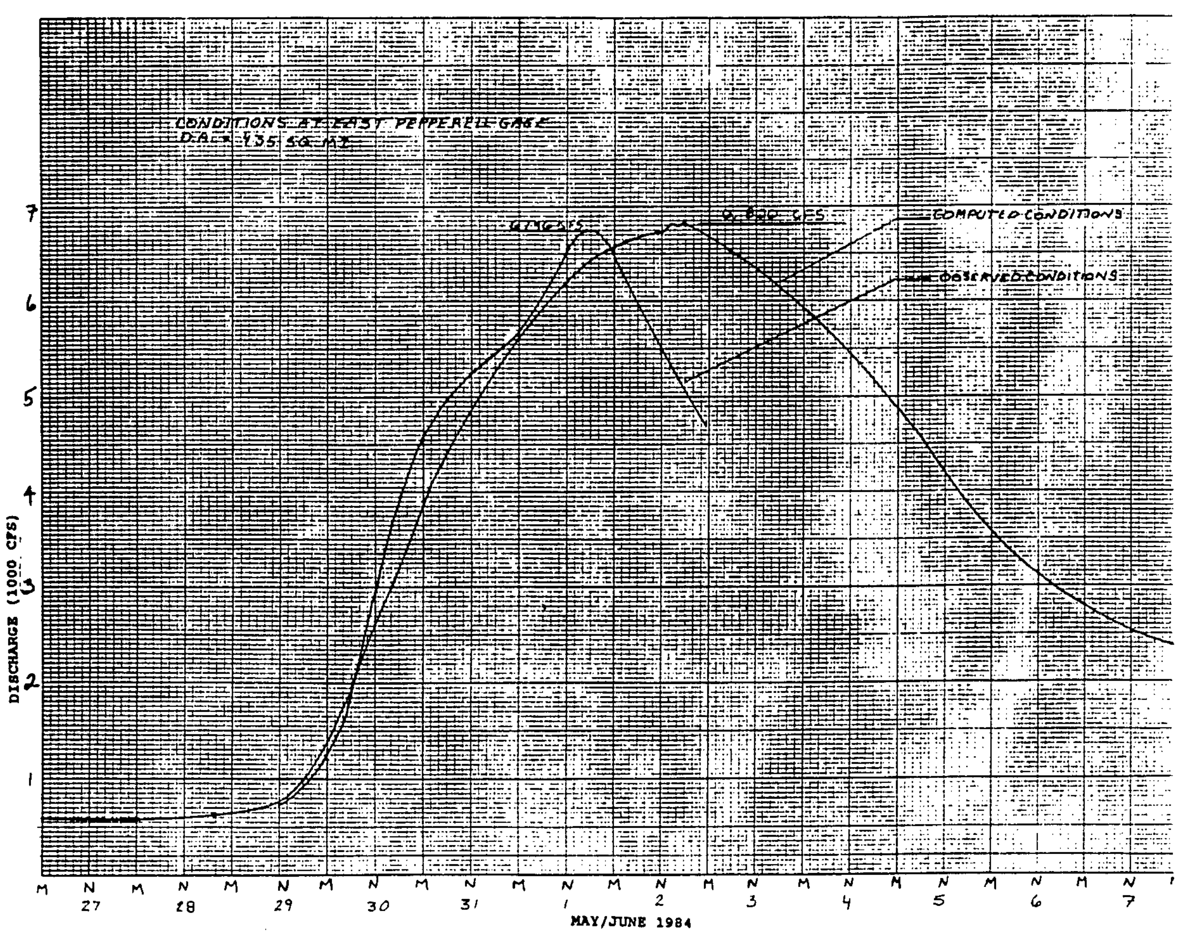
PLATE C-3



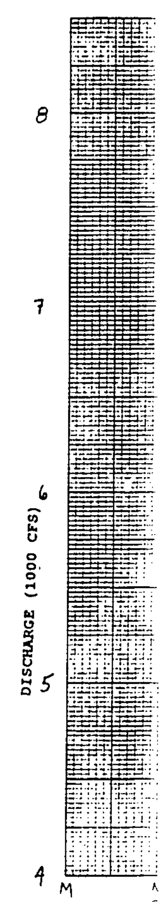
ESTIMATED INITIAL INFLOW TO STUDY REACH AT THE CONFLUENCE OF THE SOUTH BRANCH AND NORTH NASHUA RIVERS
TOTAL INFLOW TO REACH
OBSERVED FLOW AT LEOMINSTER GAGE
ESTIMATED FLOW AT CLINTON GAGE
DISCHARGE (1000 CFS)
MAY/JUNE 1984

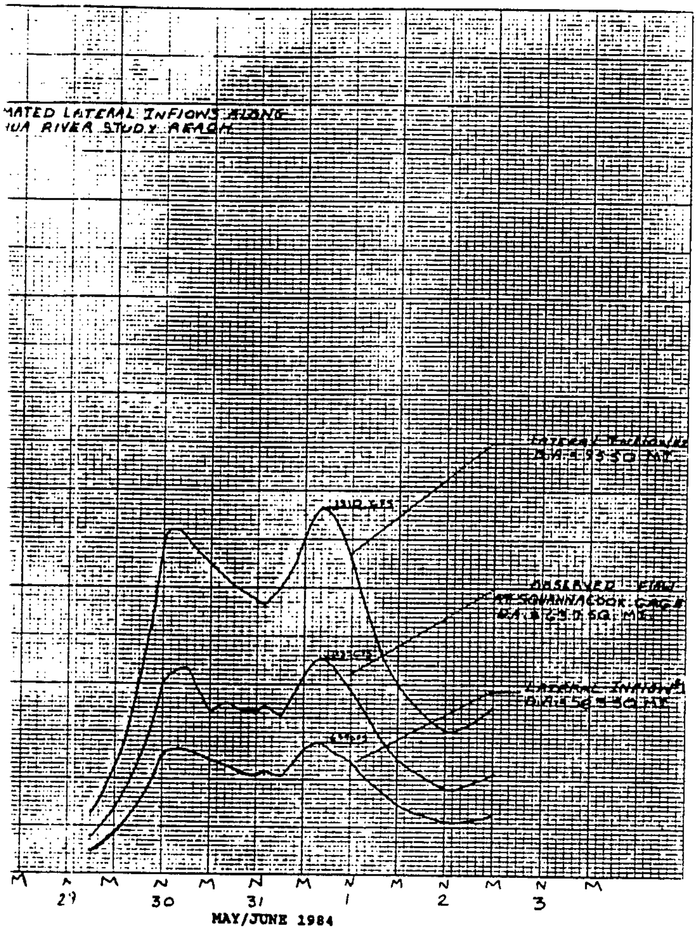
DISCHARGE (1000 CFS)

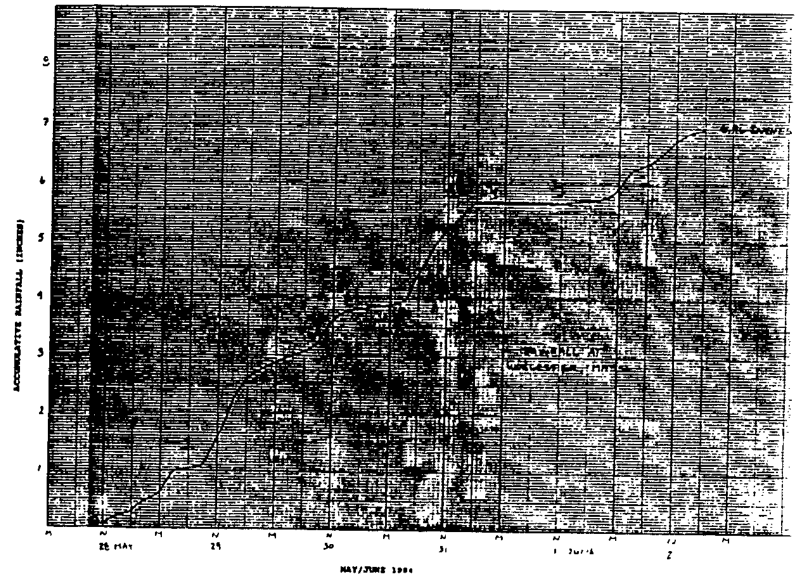



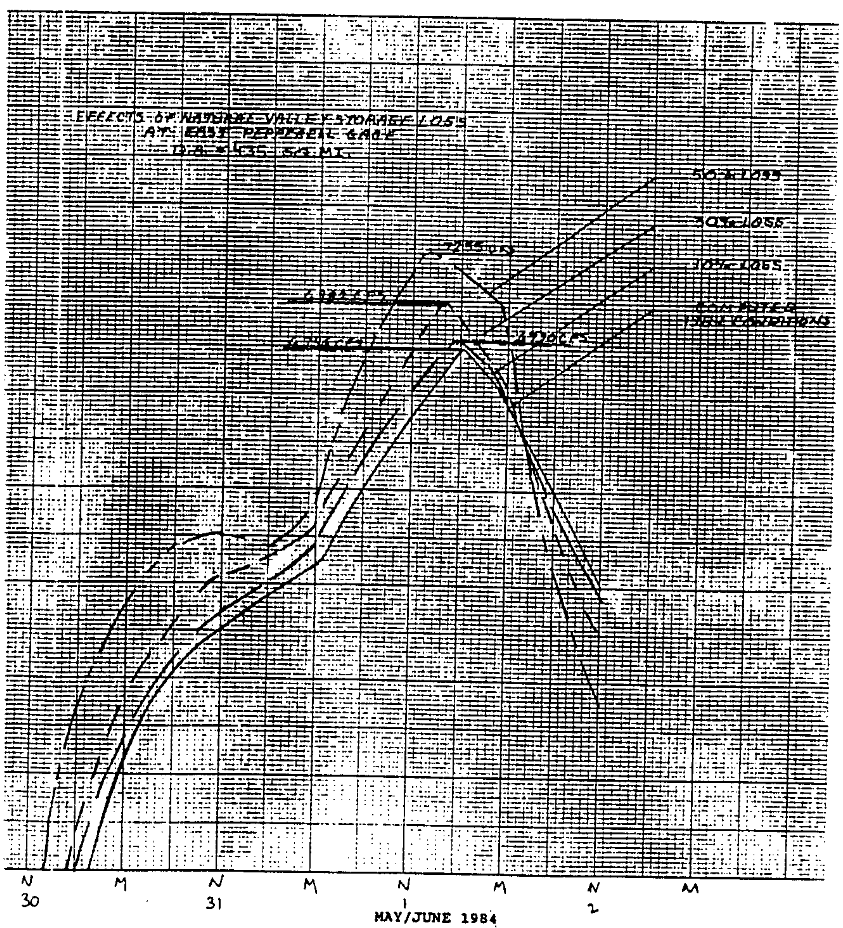
CONDITIONS AT EAST PEPPERELL GAGE
D.A.= 435 SQ. MI.
COMPUTED CONDITIONS
OBSERVED CONDITIONS
DISCHARGE (1000 CFS)
MAY/JUNE 1984

DISCHARGE (1000 CFS)



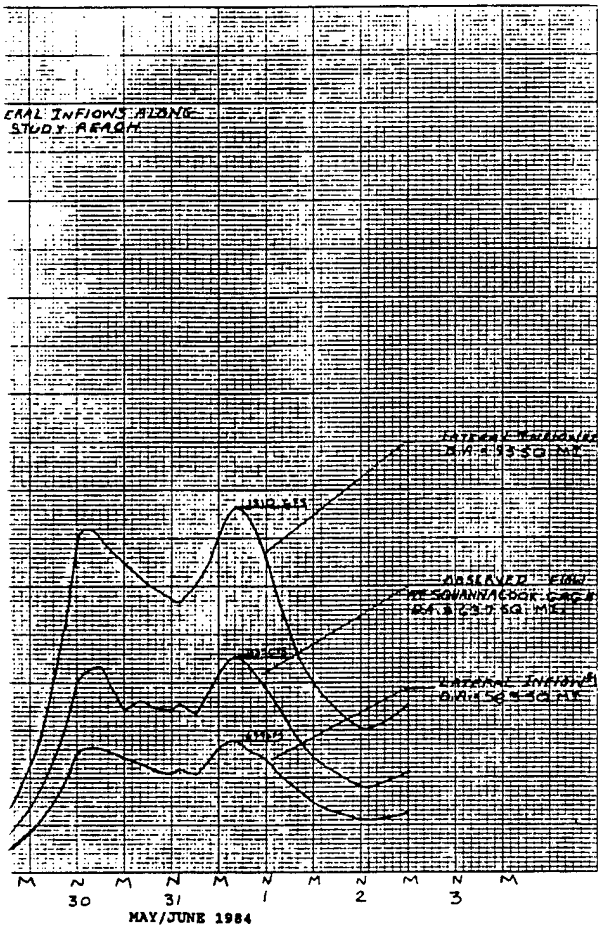

NASHUA RIVER BASIN

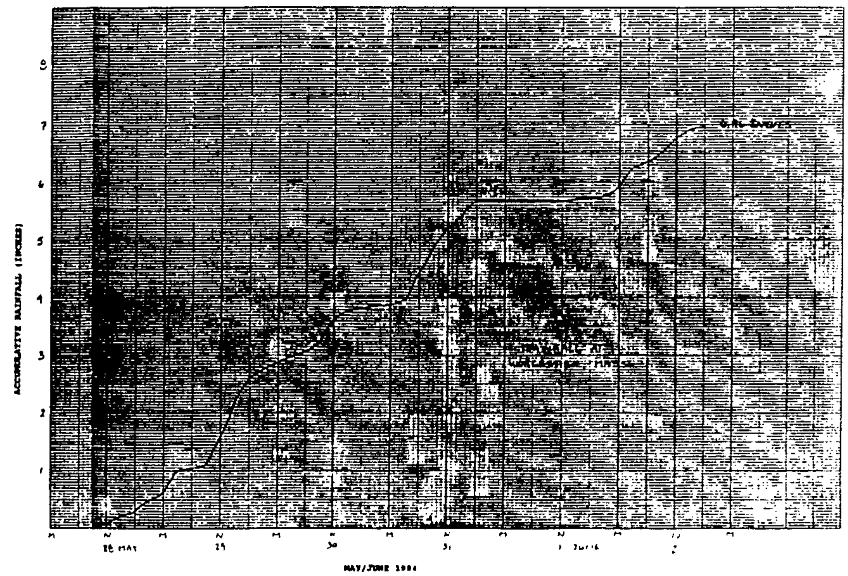
MAY/JUNE 1984 FLOOD ANALYSIS

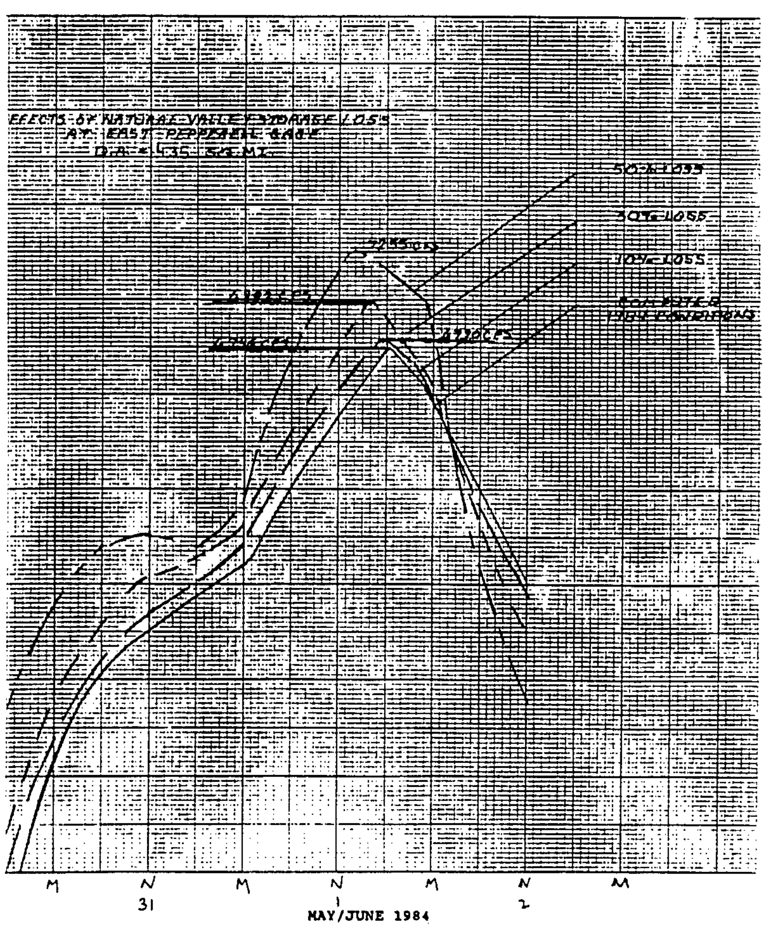
Lancaster to Pepperell Reach

H.E.B. August 1992

PLATE C-4




NASHUA RIVER BASIN

MAY/JUNE 1984 FLOOD ANALYSIS

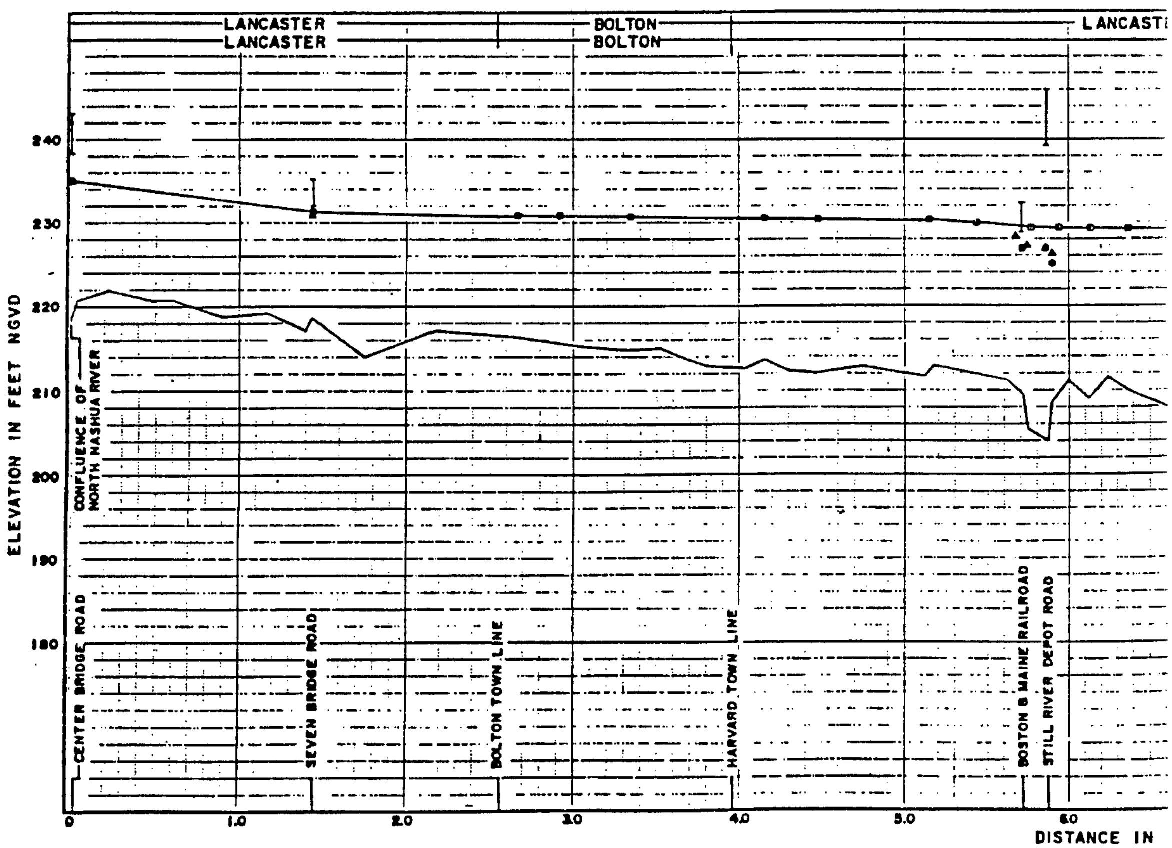
Lancaster to Pepperell Reach

H.E.B. August 1992

PLATE C-4

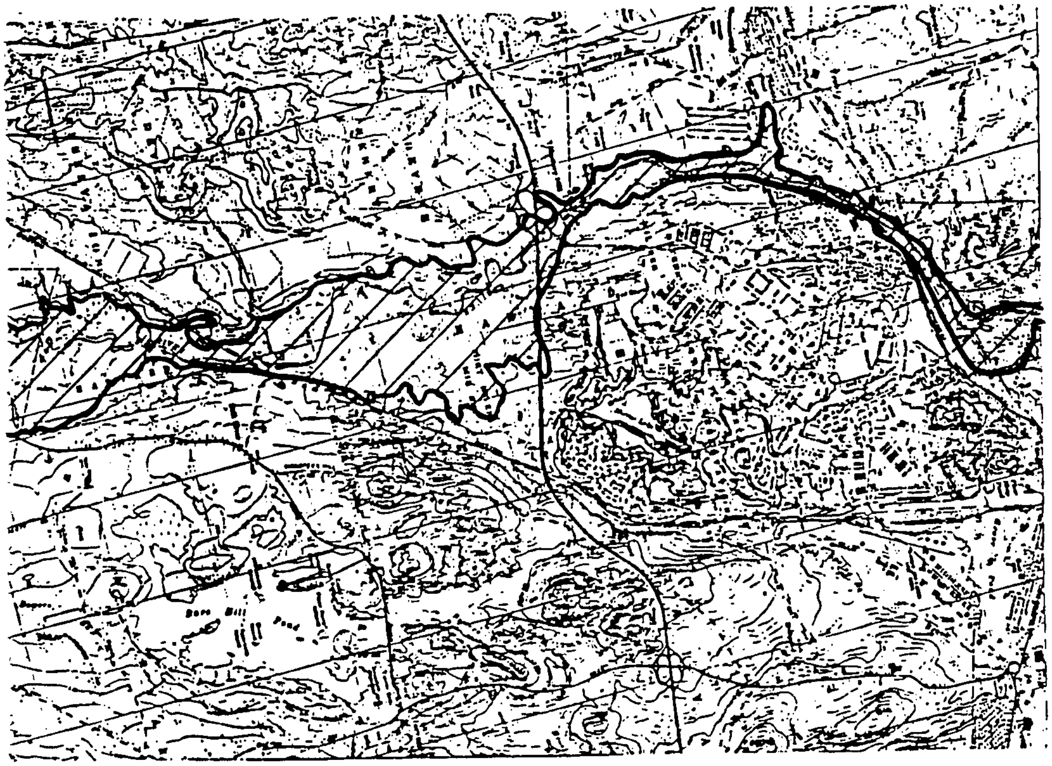
3

PLAN




PROFILE

(1)



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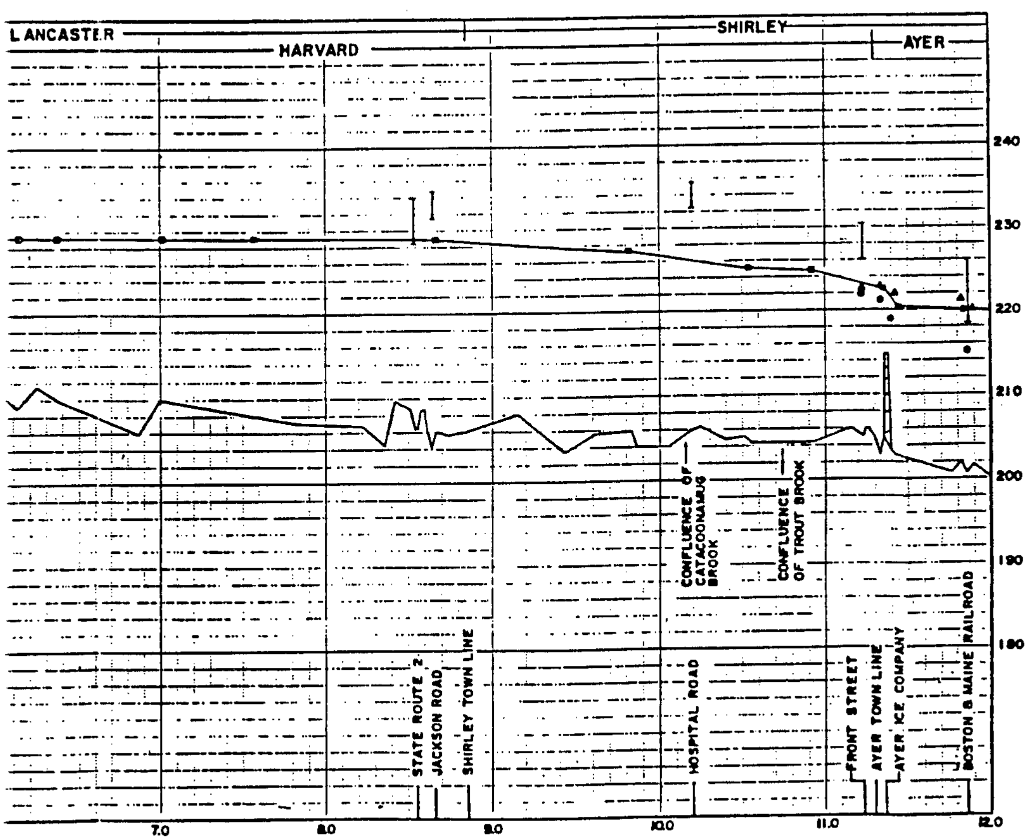



ANCE IN MILES

OFILE

## PLAN LEGEND

REPRESENTS 1936 FLOODED AREA AND STUDY STORAGE REACH

10+0 RIVER MILES ORIGINATING FROM NORTH NASHUA RIVER CONFLUENCE

## PROFILE LEGEND

△ INDICATES H.W.M. MARCH 1936

⊙ INDICATES H.W.M. SEPTEMBER 1938

—⊡— CALIBRATED PEAK STAGES FOR 1936 UNET COMPUTER MODEL

GRAPHIC SCALES:

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

NASHUA RIVER BASIN

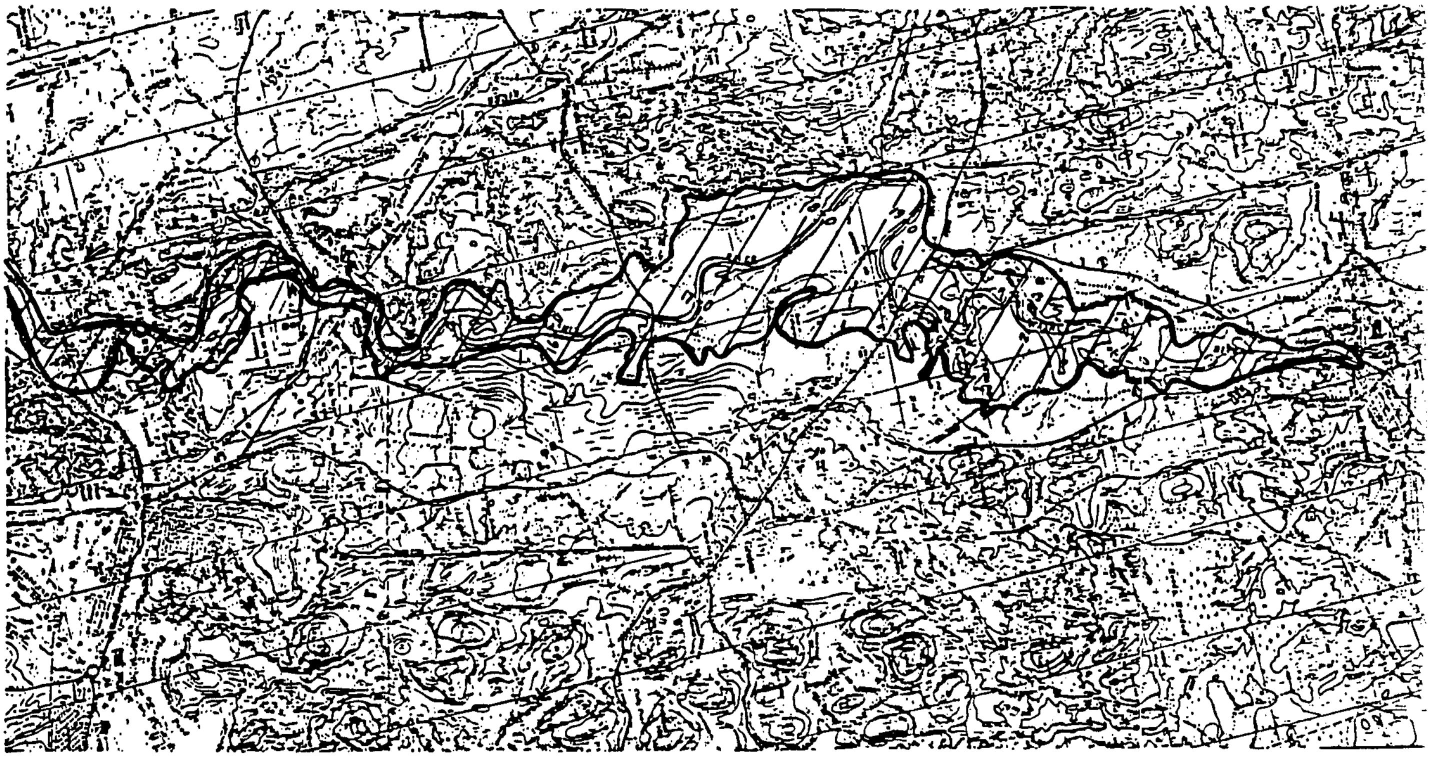
PLAN AND PROFILE

MILES 0+0 TO 12+0

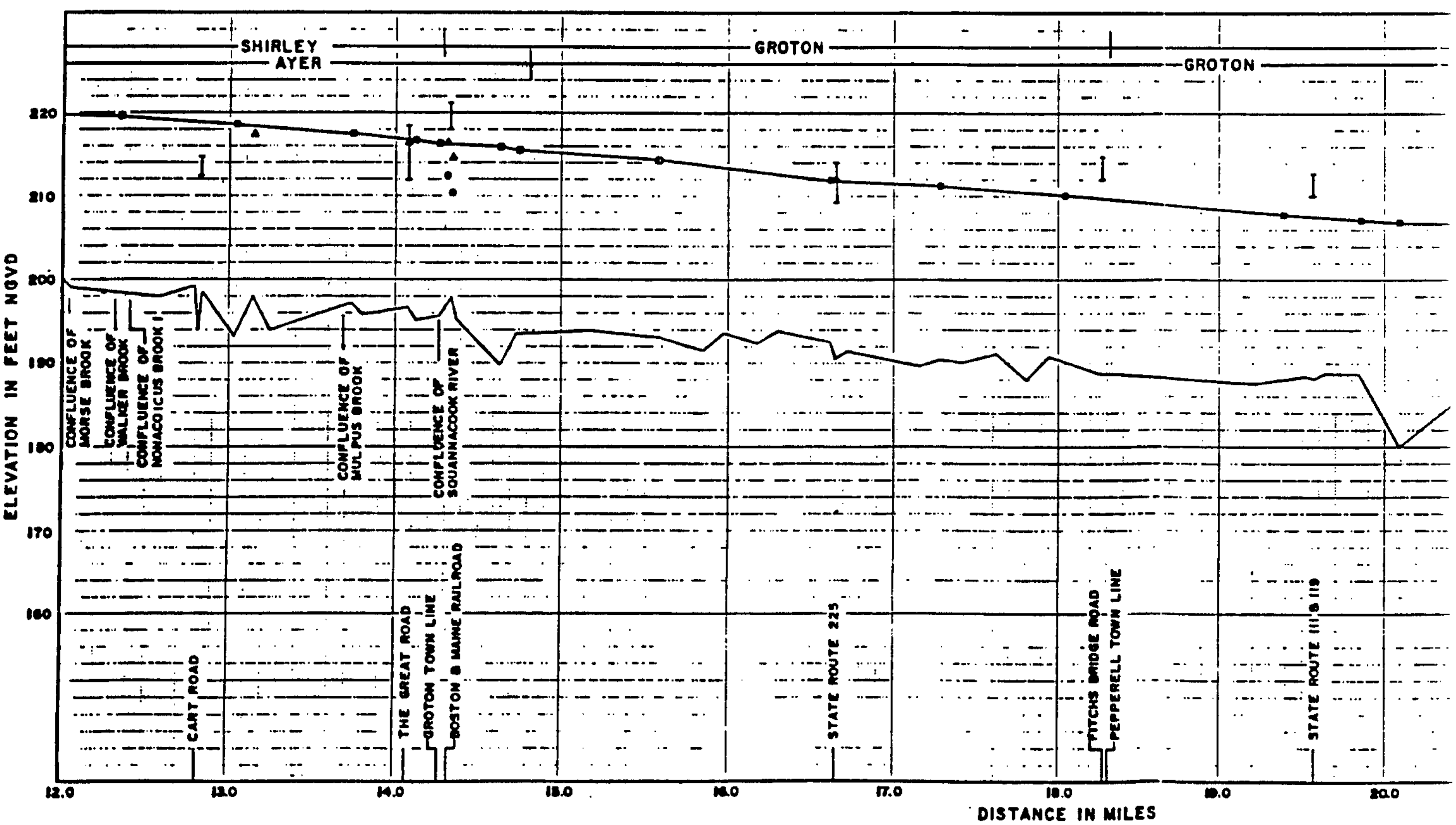
H.E.B. AUGUST 1992

PLATE C-5

(3)

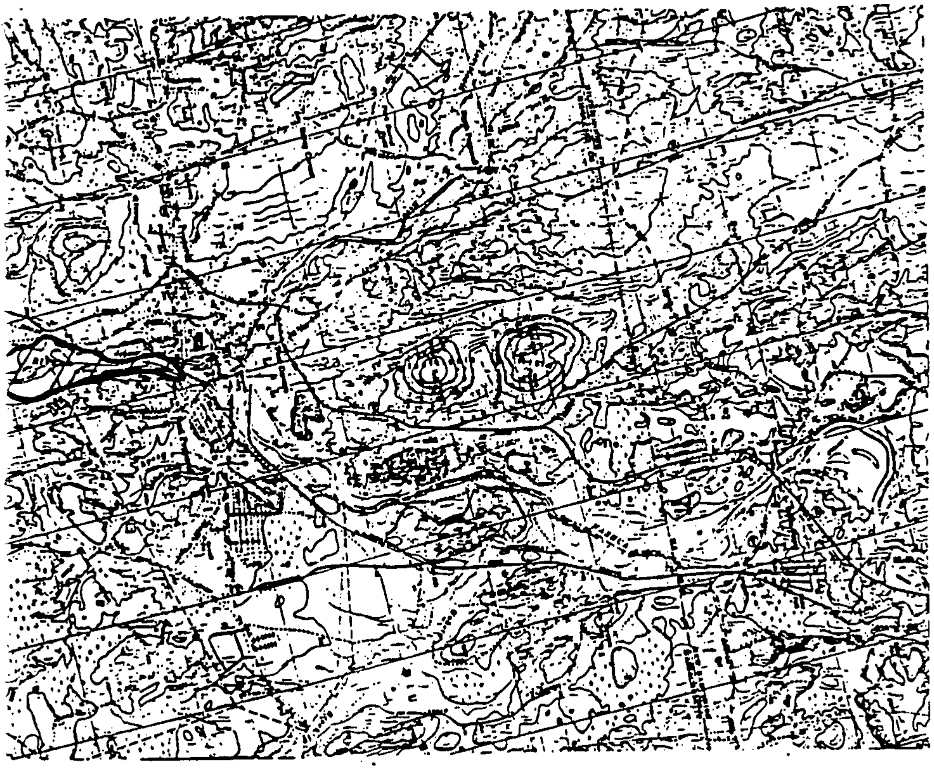


PLAN




PROFILE

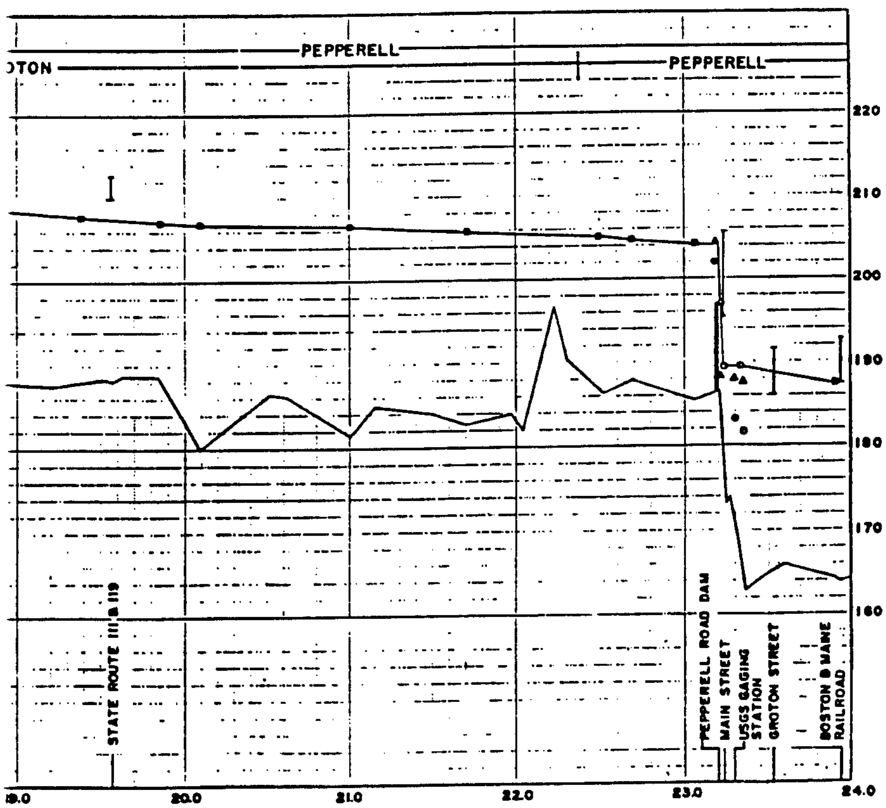
(1)



## PLAN LEGEND

REPRESENTS 1936 FLOODED AREA AND STUDY STORAGE REACH

18+0 RIVER MILES ORIGINATING FROM NORTH NASHUA RIVER CONFLUENCE




## PROFILE LEGEND

△ INDICATES H.W.M. MARCH 1936

⊙ INDICATES H.W.M. SEPTEMBER 1938

—⊡— CALIBRATED PEAK STAGES FOR 1936 UNET COMPUTER MODEL

GRAPHIC SCALES

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

NASHUA RIVER BASIN

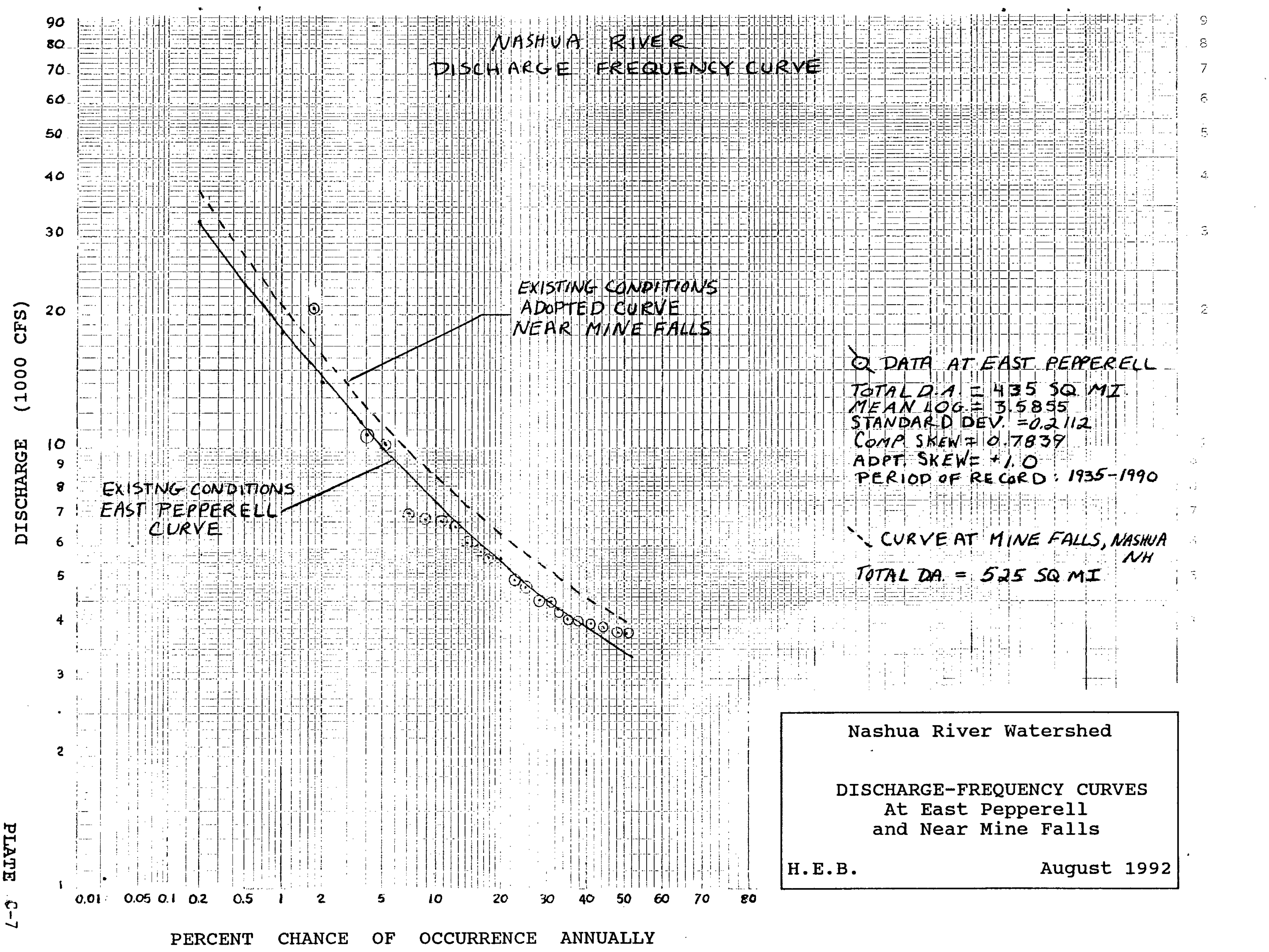
PLAN AND PROFILE

MILES 12+0 TO 24+0

N.E.D. AUGUST 1992

PLATE C-6

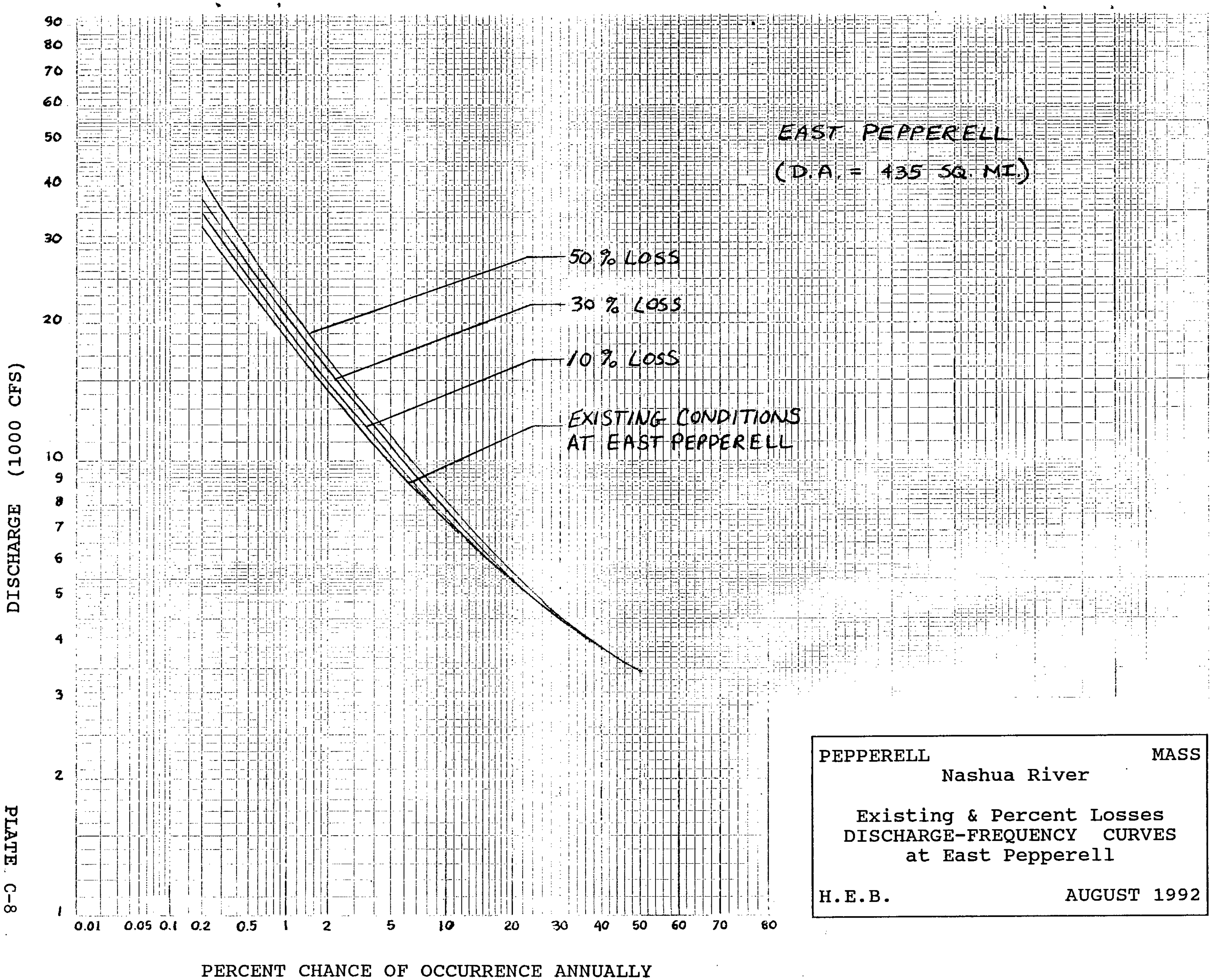
2




Nashua River Watershed

DISCHARGE-FREQUENCY CURVES
At East Pepperell
and Near Mine Falls

H.E.B. August 1992

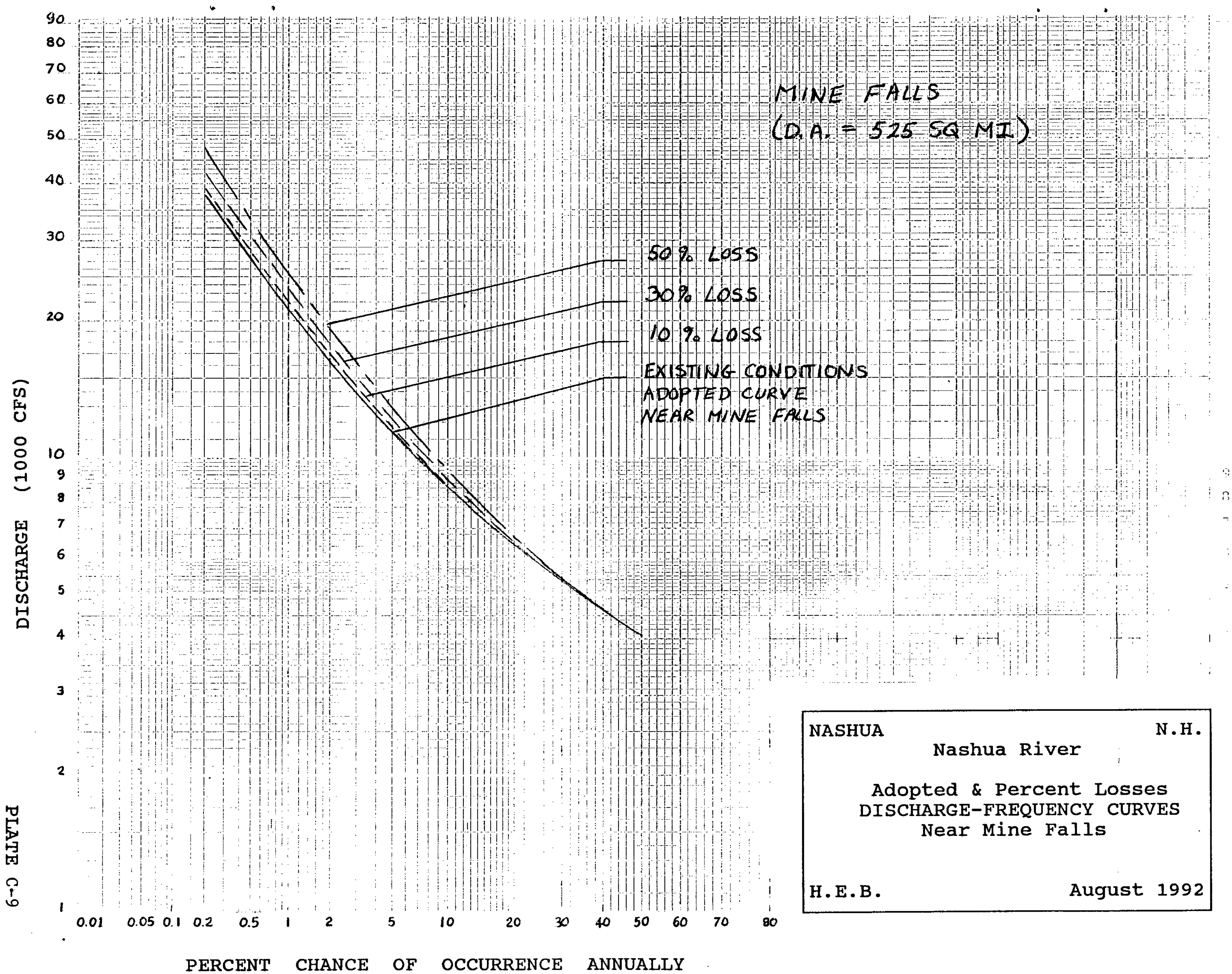



PEPPERELL MASS

Nashua River

Existing & Percent Losses
DISCHARGE-FREQUENCY CURVES
at East Pepperell

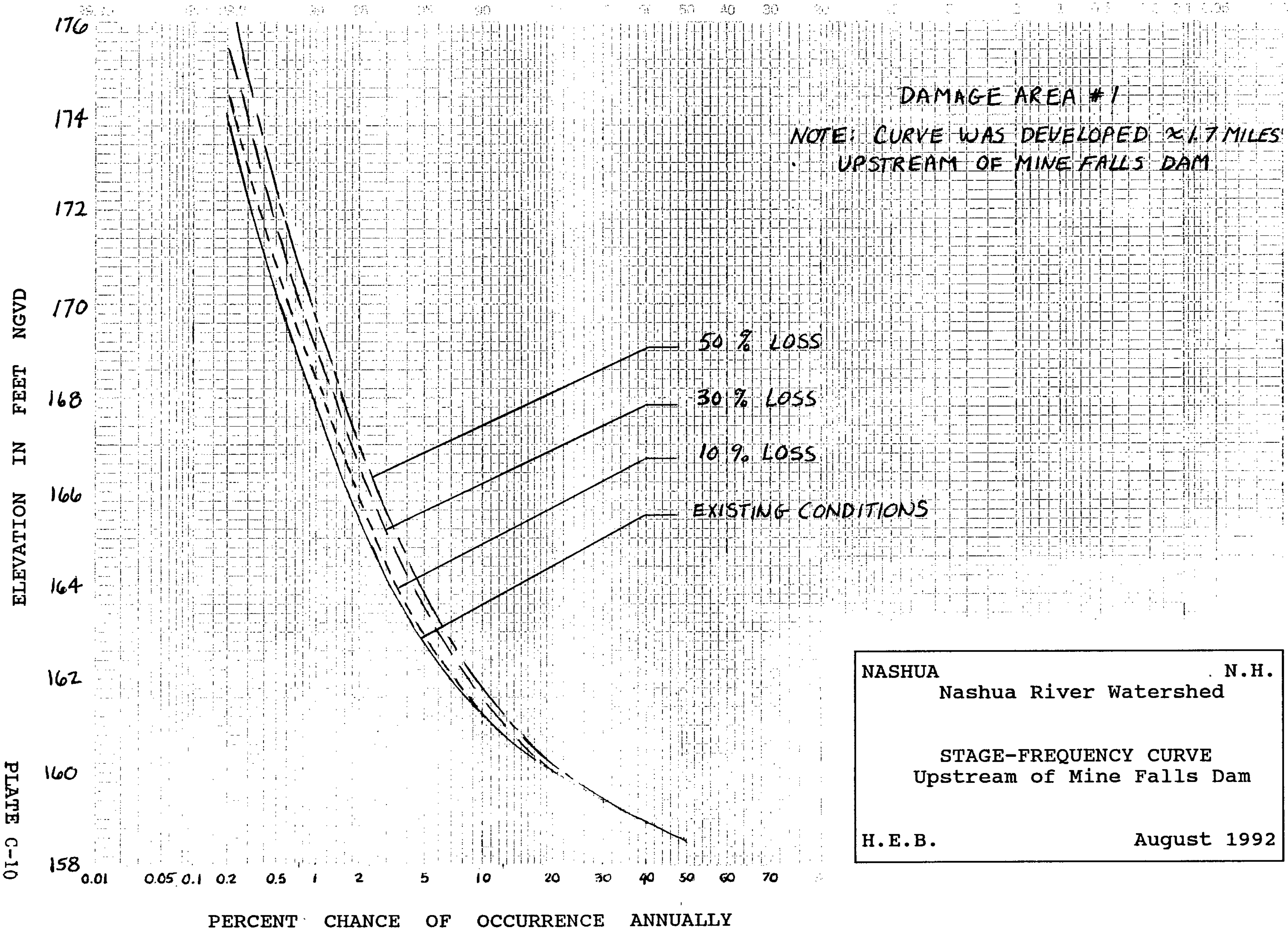
H.E.B. AUGUST 1992




NASHUA N.H.
Nashua River

Adopted & Percent Losses
DISCHARGE-FREQUENCY CURVES
Near Mine Falls

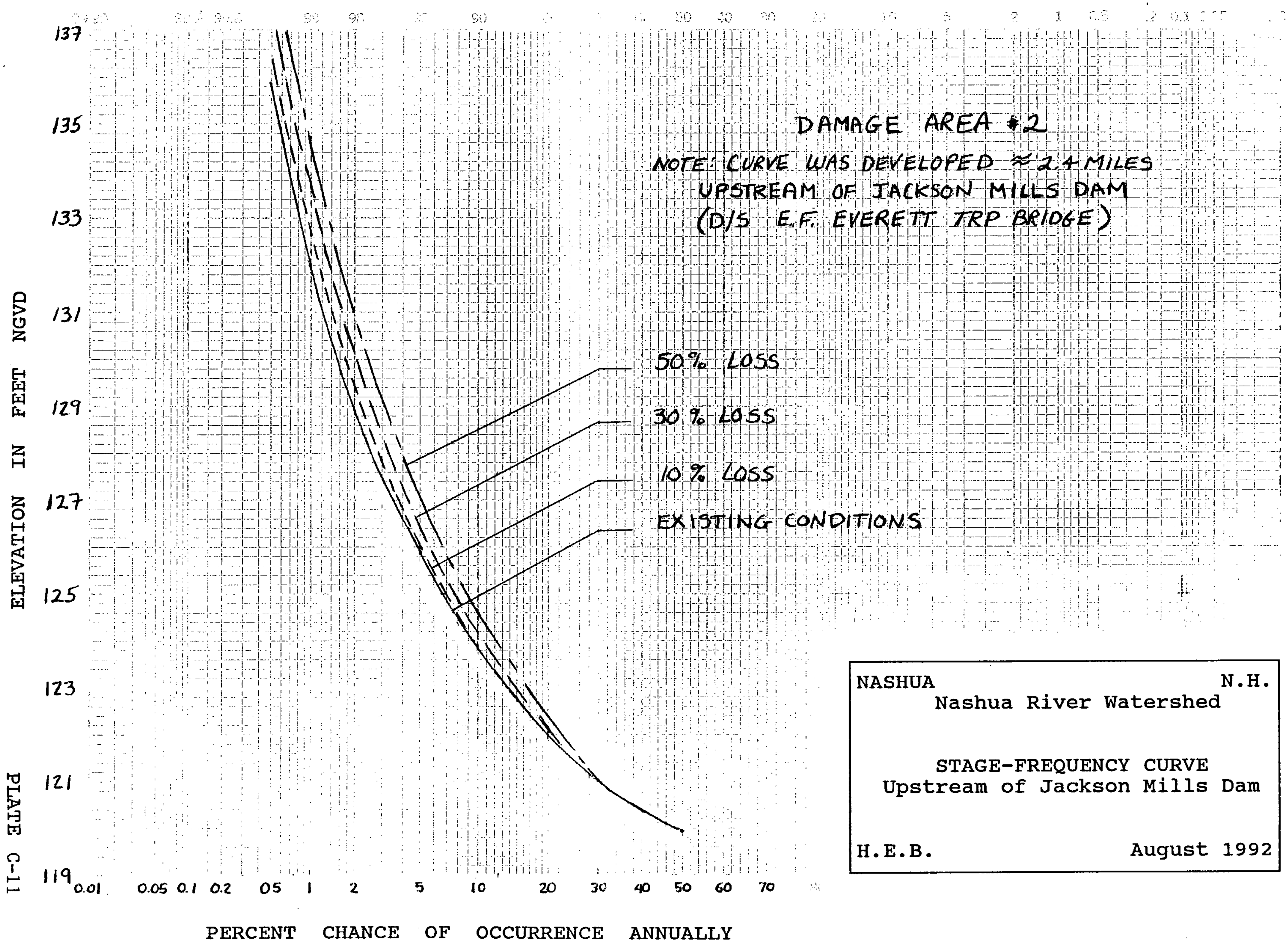
H.E.B. August 1992




NASHUA N.H.
Nashua River Watershed

STAGE-FREQUENCY CURVE
Upstream of Mine Falls Dam

H.E.B. August 1992




NASHUA N.H.
Nashua River Watershed

STAGE-FREQUENCY CURVE
Upstream of Jackson Mills Dam

H.E.B. August 1992

# APPENDIX D

# SUPPORTING ECONOMIC INFORMATION

APPENDIX D

MASSACHUSETTS NATURAL VALLEY STORAGE
INVESTIGATION - SECTION 22

SUPPORTING ECONOMIC INFORMATION

TABLE OF CONTENTS

## INTRODUCTION

The information included within this appendix was used to determine benefits and resource values in the case study.

-Tables D-1 and D-2 show Corps of Engineers guidelines for determining point and dollar values in the calculation of recreation outputs using the Unit Day Value method.

-Table D-3 lists the estimated economic values achieved as a result of carbon storage in various types of study lands.

-Tables D-4 and D-5 show the detailed cost estimates for constructing 10 acres of forested or scrub-shrub wetland and 10 acres of emergent wetland.

-Table D-6 lists the values of various wetlands and uplands based on the energy analysis technique.

Table D-1
Guidelines for Assigning Points for General Recreation

| Criteria | Judgement factors | | | | |
|---|---|---|---|---|---|
| (a) Recreation experience[1] | Two general activities[2] | Several general activities | Several general activities;one high quality value activity[3] | Several general activities; more than one high quality high activity | Numerous high quality value activities; some general activities |
| Total Points: 30<br>Point value: | 0-4 | 5-10 | 11-16 | 17-23 | 24-30 |
| (b) Availability of opportunity[4] | Several within 1 hr. travel time; a few within 30 min. travel time | Several within 1 hr. travel time; none within 30 min. travel time | One or two within 1 hr. time; none within 45 min. travel time | None within 1 hr. travel time | None within 2 hr. travel time |
| Total points: 18<br>Point value: | 0-3 | 4-6 | 7-10 | 11-14 | 15-18 |
| (c) Carrying capacity[5] | Minimum facility for development for public health and safety | Basic facility to conduct activity(ies) | Adequate facilities to conduct without deterioration of the resource or activity experience | Optimum facilities to conduct activity at site potential | Ultimate facilities to achieve intent of selected alternative |
| Total points: 14<br>Point value: | 0-2 | 3-5 | 6-8 | 9-11 | 12-14 |
| (d) Accessibility | Limited access by any means to site or within site | Fair access, poor quality roads to site; limited access within site | Fair access, fair road to site; fair access; good roads within site | Good access, good roads to site; fair access, good roads within site | Good access, high standard road to site; good access within site |
| Total points: 18<br>Point value: | 0-3 | 4-6 | 7-10 | 11-14 | 15-18 |
| (e) Environmental | Low esthetic factors[6] that that significantly lower quality[7] | Average esthetic quality; factors exist that lower quality to minor degree | Above average esthetic quality; any limiting factors can be reasonably rectified | High esthetic quality; no factors exist that lower quality | Outstanding esthetic quality; no factors exist that lower quality |
| Total points: 20<br>Point value: | 0-2 | 3-6 | 7-10 | 11-15 | 16-20 |

1 Value for water-oriented activities should be adjusted if significant seasonal water level changes occur.
2 General activities include those that are common to the region and that are usually of normal quality. This includes picnicking, camping, hiking, riding, cycling, and fishing and hunting of normal quality.
3 High quality value activities include those that are not common to the region and/or Nation and that are usually of high quality.
4 Likelihood of success at fishing and hunting.
5 Value should be adjusted for overuse.
6 Major esthetic qualities to be considered include geology and topography, water, and vegetation.
7 Factors to be considered to lowering quality include air and water pollution, pests, poor climate, and unsightly adjacent areas.

Table D-2
Conversion of Points to Dollar Values

| Point Values | General Recreation Values | General Fishing & Hunting Values | Specialized Fishing & Hunting Values | Specialized Recreation Values Other Than Fishing & Hunting |
|---|---|---|---|---|
| 0 | 2.30 | 3.38 | 16.13 | 9.22 |
| 10 | 2.69 | 3.74 | 16.53 | 10.00 |
| 20 | 3.10 | 4.09 | 16.94 | 10.75 |
| 30 | 3.61 | 4.45 | 17.37 | 11.52 |
| 40 | 4.15 | 4.90 | 17.78 | 12.30 |
| 50 | 4.94 | 5.40 | 19.41 | 13.85 |
| 60 | 5.33 | 5.87 | 21.07 | 15.37 |
| 70 | 5.74 | 6.32 | 22.73 | 18.45 |
| 80 | 6.13 | 6.58 | 24.38 | 21.52 |
| 90 | 6.54 | 6.82 | 26.02 | 24.60 |
| 100 | 6.92 | 6.88 | 27.67 | 27.67 |

Table D-3

Economic Value of Carbon Storage in the Nashua River Case Study Area

| Community Type | % of Total Storage Area | Estimated Carbon Storage $g/m^2/yr$ | Value $/acre/yr |
|---|---|---|---|
| Riverine/Open Water | 14 | 0 | 0 |
| Emergent | 2 | 75 | 60 |
| Emergent/Scrub-shrub | 3 | 360 | 290 |
| Scrub-shrub<br>Scrub-shrub/Forested | 8 | 650 | 525 |
| Forested (red maple) | 15 | 325 | 260 |
| Weighted Wetland Average | - | 270 | 220 |
| Forested Uplands | 24 | 800 | 660 |

Notes:

a. Wetland areas determined from US FWS National Wetland Inventory Maps (42 % of study area is wetland).

b. Carbon storage per acre/year for emergent vegetation is based on a peat accumulation rate of 200 cm/1000 years and peat density of 50 mg/ml (see Mitsch and Gosselink, 1985). For wetlands with woody vegetation 66 % of NPP is assumed to be stored long-term in roots, bark, branches, and wood (see Whittaker, 1975 p. 195.). Although some carbon storage occurs in riverine/open water habitats (particularly impounded areas), storage in these area is likely to be small relative to other habitats and is assumed to be zero in this analysis.

c. Value is assumed to be equal to cost of planting trees to sequester the same amount to carbon as one acre of the various community types. Planting cost is assumed to be $200 per ton carbon/year stored in 1992 dollars (see Sedgo, 1989).

Table D-4
Cost Estimate for Construction of
10 Acre Forested or Scrub-shrub Wetland[a]

| Item | Quantity | Unit Cost ($)[b] | Item Cost ($) |
|---|---|---|---|
| Study Planning[c] | - | - | 75,000 |
| Land (purchase cost) | 12 ac | 2,000/ac | 24,000 |
| Clearing and Grubbing | 11 ac | 5,000/ac | 55,000 |
| Strip and Stockpile Topsoil | 8,500 cy | 2.00/cy | 17,000 |
| Excavate to 6" Below Final Grade | 58,000 cy | 5.50/cy | 319,000 |
| Spread 6" Stockpiled Topsoil | 8,500 cy | 2.00/cy | 17,000 |
| Seeding (grasses) | 53,000 sy | 1.80/sy | 95,400 |
| Shrubs and Trees | 4,356 | 12.00 ea | 52,300 |
| Planting | 10 ac | 2,000/ac | 20,000 |
| Monitoring | - | - | 25,000 |
| Subtotal | | | 699,700 |
| Contingency (20 %) | | | 140,000 |
| Total Cost | | | 839,700 |
| Total Cost/Acre | | | say 84,000 |

Notes:

a. Cost estimate is based on following assumptions and design criteria: 1) wetland would be built in a forested upland area with level ground and minimal bedrock outcrops; 2) an average final grade 3 ft. below existing grade would be needed provide adequate groundwater moisture to support wetland trees and shrubs; 3) site would be excavated to 6" below final grade and backfilled with stockpiled topsoil; 4) container grown trees and shrubs would be planted at 10 ft. centers; 5) site would be seeded with perennial grasses to provide vegetative cover until tree and shrub canopy developed.

b. Unit costs are from recent government cost estimates for wetland replacment projects and wetland plant nursery catalogs. Real estate cost is based on maximum price payed by Commonwealth of Massachusetts for conservation land.

c. Planning costs include the necessary engineering services (e.g. design layout, topographical surveys, subsurface borings, specifications), environmental studies (e.g. archaeological survey, endangered species survey), real estate services, and project management.

Table D-5

Cost Estimate for Construction of
10 Acre Emergent Wetland[a]

| Item | Quantity | Unit Cost ($)[b] | Item Cost ($) |
|---|---|---|---|
| Study Planning[c] | - | - | 75,000 |
| Land (purchase cost) | 12 ac | 2,000/ac | 24,000 |
| Clearing and Grubbing | 11 ac | 5,000/ac | 55,000 |
| Strip and Stockpile Topsoil | 8,500 cy | 2.00/cy | 17,000 |
| Excavate to 6" Below Final Grade | 75,000 cy | 5.50/cy | 412,500 |
| Spread 6" Stockpiled Topsoil | 8,500 cy | 2.00/cy | 17,000 |
| Plant Material | 50,000 | 1.00 ea | 50,000 |
| Planting | 10 ac | 5,000/ac | 50,000 |
| Monitoring | - | - | 25,000 |
| Subtotal | | | 725,500 |
| Contingency (20 %) | | | 145,100 |
| Total Cost | | | 870,600 |
| Total Cost/Acre | | | say 88,000 |

Notes:

a. Cost estimate is based on following assumptions and design criteria: 1) wetland would be built in a forested upland area with level ground and minimal bedrock outcrops; 2) an average final grade 4 ft. below existing grade would be needed provide adequate groundwater moisture to support emergent vegetation; 3) site would be excavated to 6" below final grade and backfilled with stockpiled topsoil; 4) rhizomes or seedlings would be planted at 3 ft. centers.

b. Unit costs are from recent government cost estimates for wetland replacment projects and wetland plant nursery catalogs. Real estate cost is based on maximum price payed by Commonwealth of Massachusetts for conservation land.

c. Planning costs include the necessary engineering services (e.g. design layout, topographical surveys, subsurface borings, specifications), environmental studies (e.g. archaeological survey, endangered species survey), real estate services, and project management.

Table D-6

Economic Value of Study Area Wetlands and
Forested Uplands Based on the Energy Analysis Technique

| Community Type | % of Total[a] Wetland Area | Net Primary Productivity[b,c] $g/m^2/yr$ | $kcal/m^2/yr$ | Value \$ acre/yr[d] |
|---|---|---|---|---|
| Riverine/Open Water | 33 | 250 | 1100 | 19 |
| Emergent | 5 | 1600 | 7100 | 121 |
| Emergent/Scrub-shrub | 7 | 1300 | 5750 | 97 |
| Scrub-shrub Scrub-shrub/Forested | 19 | 1000 | 4450 | 75 |
| Forested (red maple) | 36 | 500 | 2200 | 38 |
| Weighted Wetland Average | - | 625 | 2750 | 47 |
| Forested Uplands (24 % of study area) | - | 1200 | 5300 | 90 |
| Old-field | - | 600 | 2650 | 45 |

Notes:

a. Wetland areas determined from US FWS National Wetland Inventory Maps (42 % of study area is wetland).

b. Net primary production is based on values reported in the literature (Whittaker, 1975; F. Brinson et al., 1981; F. Oulette, Univ. of Rhode Island, pers. commun.) and professional judgment. NPP includes both above and belowground production. Scrub-shrub and forested wetland NPP is based on aboveground NPP values reported in literature, with 25 percent added for belowground NPP. Determination of actual net primary production in the study area was beyond the scope of this project.

c Assumes 1 g biomass = 4.43 kcal (Whittaker, 1975).

d. Productivity to dollar value conversion factor was adopted from Costanza et al. (1989), and updated in 1992 dollars.

# APPENDIX E

## SAMPLE CONTINGENT VALUE SURVEY

## Sample Contingent Value Survey

### Benefits and Costs of Natural Valley Storage Preservation

Natural valley storage are lands adjacent to streams or rivers that are periodically flooded. The land may be either wet throughout much of the year or inundated only during rare flood events.

Preservation of natural valley storage provides many benefits. These include:

- natural storage of water during flood events to reduce downstream flooding
- open space for recreation activities such as hiking, hunting, fishing, and bird watching
- possible improved water quality
- habitat for many species of wildlife and plants, including some that may be rare and threatened with extinction
- commercial products such as furs, crops, and timber

Preservation of natural storage areas requires that some potential uses of the land be given up. These include construction of housing, industrial or commercial facilities, and roads. Jobs and tax benefits could be lost to local communities as a result of these restrictions.

### Study Area

Our study focuses on the Nashua River in central Massachusetts. The study area extends along a 22 mile reach of the river, from its confluence with the North Nashua River in Lancaster, to Pepperell. The natural storage areas along this reach comprise an area of about 7.5 square miles (4,800 acres).

Residential and commercial development within the study area is currently sparse. About 70 percent of the study area is protected from future development. Most of the protected area is conservation land owned by private organizations, towns, the state of Massachusetts, or the Federal government. Major conservation areas within the study area include the Bolton Flats Wildlife Management Area, Oxbow National Wildlife Refuge, and the Rich State Forest. Additional lands within the study area are privately held, and protected from development by conservation easements.

About 40 percent of the area is wetland. Twenty five percent of the area is forested upland. Most of the remaining area is cropland or abandoned fields. Extensive natural grasslands are present at the Bolton Flats.

Uplands and wetlands in the area provide habitat for numerous species of birds, mammals, reptiles, and plants. Rare, threatened or endangered species are known to occur in the project area. Most of these occur in wetlands.

Recreational use of conservation areas and private lands within the area is high. Popular activities include canoeing, fishing, hiking, horseback riding, and cross country skiing. The Bolton Flats and Oxbow National Wildlife Refuge are reportedly among the best birding spots in Massachusetts.

Please take a few minutes to review this information and look at the photographs provided. [several photographs of the study area would be provided]

<u>Proposed Natural Valley Storage Protection Fund</u>

A recent proposal would establish a statewide Natural Valley Storage Protection Fund. Money from the Fund would be used to purchase areas threatened by development. Households would be asked to donate money to the Fund to aid in their protection. No tax dollars would be expended for the Fund.

If current trends continue 10 percent of storage lands in the study area (480 acres) will be developed within the next 50 years. This will result in increased risk of flooding in downstream communities, loss of open space for recreation, and loss of wildlife habitat. Areas lost will be primarily uplands, since most wetlands in the study area are already preserved as conservation land and are protected by strong state wetland protection laws.

<u>Contributions to the Natural Valley Storage Protection Fund</u>

After carefully considering the above information, how much would your household be willing to contribute each year to preserve natural valley storage areas from development? $______

Also, please answer the following questions:

1. How many miles do you live from the study area? ______
(respondent would be referred to map with concentric mileage circles originating at the study area).

2. Have you ever visited the study area for recreational purposes (e.g. to hike, hunt, fish, canoe, or observe wildlife)?
Yes _____ No _____

3. Have you occasionally visited similar areas elsewhere for recreational purposes? Yes _____ No _____

4. How familiar were you with the benefits of preserving floodplains before reading the background material provided with this survey?
Not Familiar _____ Somewhat Familiar _____ Very Familiar_____

5 In the past year have you donated money to conservation organizations? Yes _____ No _____

6. Are you male or female _______

7. How many people are in your household? _______

8. What is you age? _______

9. What is your weekly household income? _______